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Barium-felspars (celsian and paracelsian) from Wales.

By L. J. Spencer, C.B.E., M.A., Sc.D., F.R.S.

Formerly Keeper of Minerals in the British Museum.

[Read November 6, 1941.]

In 1911 an interesting find of barium-felspars was made in the Benallt manganese mine near Rhiw in the Lleyn peninsula of Carnarvonshire. A brief preliminary note on the occurrence was given by Mr. Arthur Russell in the same year.[1] At the same time he very generously handed over to me for crystallographic and optical description a selection of the material he had collected, while he himself made a start on the chemical analysis of the material. Chemical analyses have now, at last, been made by Miss Hilda Bennett in the Mineral Department of the British Museum, and it therefore seems time to collect together the large volume of notes on the work done in 1911.

The material was found in some abundance in a band in shales and sandstones of Ordovician age with associated lava flows and beds of volcanic tuff, and beds of black manganese ore. The unoxidized ore is mainly carbonate with some silicate.[2] Nearby there is an intrusive sill of dolerite, and probably the barium-felspars are the result of metamorphic action. The geology of the district has been described by Dr. C. A. Matley[3] and the petrography by Dr. A. W. Woodland.[4] In the same mine came fine crystals of natrolite, which have been further examined by Dr. M. H. Hey.[5] In none of these publications has any mention been made of the barium-felspars.

The crystals of the barium-felspar are of two totally distinct types. One of them, described under celsian, presents the form of monoclinic crystals of typical felspar (adularia) habit. The other, paracelsian, is pseudo-orthorhombic and is the more interesting and puzzling of the two.

1. A. Russell, An occurrence of the barium-felspar celsian in north Wales. Nature, London, vol. 86, p. 180.
2. H. Dewey and others, Tungsten and manganese ores. Mem. Geol. Surv., Special Reports on Mineral Resources of Great Britain, 1915, vol. 1, p. 49; 3rd edit., 1923, p. 71. A. W. Groves, Manganese. Reports on the Mineral Industry of the British Empire and foreign countries, Imperial Institute, London, 1938, 2nd edit., p. 31.
3. C. A. Matley, Quart. Journ. Geol. Soc. London, 1932, vol. 88, pp. 245, 246, 248, 249, 263; Proc. Geol. Assoc. London, 1939, vol. 50, p. 99.
4. A. W. Woodland, The petrography and petrology of the manganese ore of the Rhiw district (Carnarvonshire). Proc. Geol. Assoc. London, 1939, vol. 50, pp. 205–222. [M.A. 8–250.]
5. M. H. Hey, Min. Mag., 1932, vol. 23, pp. 246, 248, 251–253, 257–260, 273.

Paracelsian.

The crystals of paracelsian have the form of simple orthorhombic crys
from which they cannot be distinguished by goniometric measurements.
when examined optically in thin sections they show complex twinning of m
than one kind. The name 'paracelsian' (of E. Tacconi, 1905) was provisiona

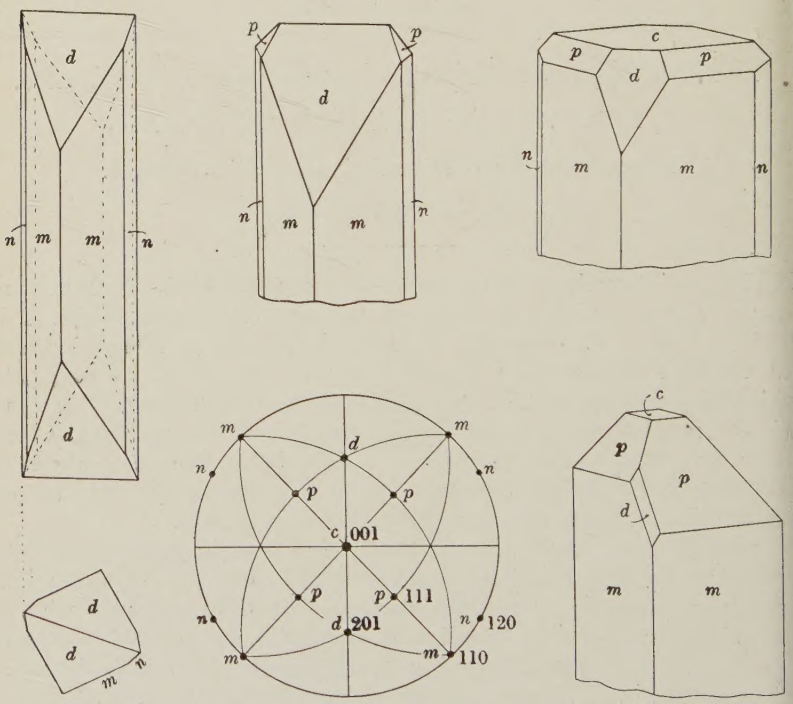

Fig. 1. Paracelsian crystals of simple orthorhombic habit from Benallt mine, Carnarvonshire; and stereographic projection of the few crystal-forms.

adopted for these crystals in 1911 and it may be retained here. The prefix pa
(παρά near) may suitably be applied to apparently dimorphous forms which c
be explained by complex twinning, especially when there is no difference
specific gravity, as, for example, paracoquimbite, parahilgardite, paralaurioni
pararammelsbergite, parawollastonite, paratacamite.

The crystals (fig. 1) are prismatic in habit with very few crystal-forms, and w
very much the aspect of crystals of topaz. They range from colourless a
transparent to white and cloudy, and have a vitreous lustre. Clusters of cryst
are confusedly aggregated together in open or more or less compact masses, a
they are in part coated with oxides of iron and manganese. The largest cryst
measure 5 cm. in length with a thickness of about 1 cm.; others are only a f
millimetres. The specific gravity is 3·31–3·32, and the hardness rather less thar

In the orientation shown in fig. 1 the orthorhombic axial ratios are:

$$a : b : c = 0{\cdot}9470 : 1 : 0{\cdot}8956,$$

ulated from the measured angles mm''' (110) $(1\bar{1}0) = 86° 53'$ (limits 86° 36′–9′) and cd (001)(201) = 62° 8′ (limits 61° 55′–62° 26′). The calculated angles ne very few crystal-forms to the three axial planes (only one of which is actually ent) are:

TABLE I. Crystal-forms and calculated angles of paracelsian.
$a : b : c = 0{\cdot}9470 : 1 : 0{\cdot}8956$

Forms.	Angles to: a(100).	b(010).	c(001).
c(001)	90° 0′	90° 0′	—
m(110)	43 26½	46 33½	90° 0′
n(120)	62 10	27 50	90 0
d(201)	27 52	90 0	62 8
p(111)	54 50	56 57	52 29

ne faces in the prism zone are striated vertically and between m and n gave ies of measurements ranging from 3° 6′ to 16° 30′ from m, corresponding to nge of vicinal faces from (780) to (7.13.0). The crystals are usually symmetri- developed, as shown in the three upper drawings in fig. 1, and they are often bly terminated. Some show an irregular development; e.g. one crystal with ces at one end and a c face at the other end. Sub-parallel growth in the tals gives rise to scattered reflections. A side-growth can sometimes be lily detached, showing a contact surface parallel to (100), which is striated ontally.

ne fracture is sub-conchoidal. Cleavage is not conspicuous and seems to be erratic. It was sometimes noticed parallel to m(110). One crystal showed ght and smooth cleavage parallel to (110) but a less good and interrupted age parallel to $(1\bar{1}0)$. On another crystal cleavages could be developed llel to only three of the four m faces (suggesting that the crystal is twinned). her showed good cleavages with pearly lustre parallel to all four faces.

ne axial ratios and a glance at the stereographic projection in fig. 1 at once st a pseudo-cubic arrangement, and the angles are not far from the corre- ding cubic angles, as shown below. The agreement here is much closer than e 'hypocubic' orientation of the felspars.[1]

	Cubic		Cubic
(100)(110) = 43° 26½′	45° 0′	(001)(111) = 52° 29′	54° 44′
(001)(101) = 43 24		(100)(111) = 54 50	
(001)(011) = 41 51		(010)(111) = 56 57	
(111)(1̄11) = 70 20	70 32	(100)(201) = 27 52	26 34
(111)(11̄1) = 66 6		(010)(120) = 27 50	

ere is, however, a much closer and very remarkable agreement between ngles of paracelsian and those of topaz and danburite.[2] Interchanging the a b axes of paracelsian and taking p(111) as (121), the axial ratios and the sponding angles are:

Tables comparing the angles of felspars with cubic angles are given by P. Niggli, Lehrb. 2 d edit., 1926, vol. 2, p. 548; and E. Schiebold (1931, pp. 256, 258).

elationship between the crystal-structure of felspar and danburite has been described Schiebold (1931, p. 305), and by W. H. Taylor (Zeits. Krist., 1933, vol. 85, p. 439). 5–473.]

Paracelsian.	Topaz.	Danburite.
$BaAl_2Si_2O_8$	$[Al(F,OH)_2]_2Al_2Si_2O_8$	$CaB_2Si_2O_8$
0·5280 : 1 : 0·4728	0·5285 : 1 : 0·4770	0·5444 : 1 : 0·4807
$(100)n = 27° 50'$	$am(100)(110) = 27° 51\frac{1}{2}'$	$am(100)(110) = 28° 34'$
$(100)m = 46 \ 33\frac{1}{2}$	$al(100)(120) = 46 \ 35\frac{1}{2}$	$al(100)(120) = 47 \ 26$
$cd = 62 \ 8$	$cy(001)(041) = 62 \ 20\frac{1}{2}$	$cw(001)(041) = 62 \ 31\frac{1}{2}$
$cp = 52 \ 29$	$cv(001)(121) = 52 \ 42\frac{1}{2}$	$cr(001)(121) = 52 \ 33$

It has not been possible to trace any relationship between the angles of pa celsian and those of normally developed felspar. As shown by the optical char ters, the apparently simple orthorhombic crystals are in reality complex tw according to more than one law. But, again, it has not been possible to correl these with the twins of normal felspar. No re-entrant angles between exter faces due to twinning have been observed.

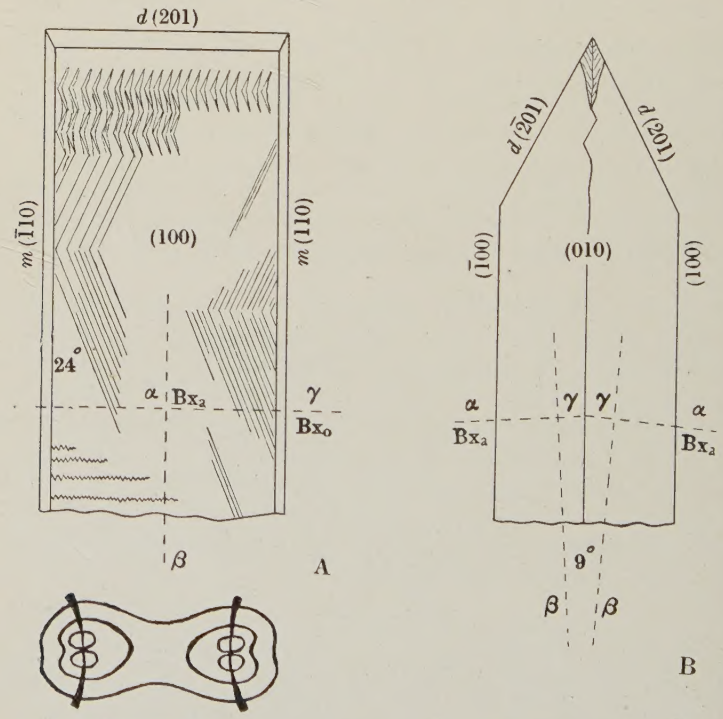

FIG. 2. Paracelsian from Benallt mine, Carnarvonshire.

A. Section parallel to (100) and nearly perpendicular to the acute bisectrix of the optic a showing complex lamellar twinning.

B. Section parallel to (010) and perpendicular to the obtuse bisectrix, showing a sim contact twin on (100) and lamellar twinning parallel to (201).

Fig. 2 gives diagrammatic representations of sections cut parallel to the pi koids (100) and (010). The (010) section (fig. 2B) shows a simple twinning (100) with an angle of 9° between the directions of optical extinction in the t halves. The (100) section (fig. 2A) gives straight extinction (parallel to the pri edge) and is nearly normal to the acute bisectrix of the optic axes. It show peculiar overlapping optic picture with double eyes about the horizontal li

acute bisectrices of the two portions of the twin are thus not quite normal (100), and the two nearly coincident optic axial planes are not quite parallel (001), being slightly tilted in opposite directions. The optical sign is negative. positive figure about the obtuse bisectrix is seen in oil through (010). Moving e sections about on the microscope stage, these optic pictures perform strange cs. Passing over the twin junction in the (010) section, the picture is suddenly ed sideways. In the (100) section the two sets of coloured rings are constantly nging in size and number, and one set may gradually pass out completely, ing a normal picture not quite in the centre of the field. This results from rying relative thickness in the two halves of the twin: in the (010) sections junction line is not always parallel to the prism edge (as represented in 2B).

he (100) section (fig. 2A) shows another peculiarity. When near the position ptical extinction between crossed nicols, a complex herring-bone structure mes evident for the first time, together with longer bands and serrated lines. se indicate lamellar twinning in two directions, apparently on the dome (083). ions parallel to (010) showed little evidence of this lamellar twinning, except sionally at the tip of the crystal (fig. 2B). Sections parallel to (001) showed e faint twin lamellae when near the position of optical extinction (the extinc- direction bisecting the angles between the prism edges). On the sub- hoidal fracture of the crystals ripple markings, resembling those shown by thyst, are sometimes seen. One clear and transparent crystal examined with agnifying lens showed, at certain inclinations of the light, internal reflections n this lamellar structure.

ith these complications it was not possible to cut from the crystals correctly accurately oriented plates for the measurement of the optic axial angle and ms for determining the refractive indices. Several prisms were cut with the acting edges parallel to [010], [100], and [001], but somewhat variable results e obtained.

wo prisms cut from the same crystal gave:

	α.	γ.	β.	γ.	$\gamma-\alpha$.
Li	1·5679	1·5832	1·5806	1·5835	0·0153
Na	1·5712	1·5866	1·5839	1·5869	0·0154
Tl	1·5744	1·5899	1·5871	1·5901	0·0155

easured pairs on other crystals were:

	α.	γ.	β.	γ.	β.	γ.	α.	β.
... ...	1·5682	1·5833	1·5836	1·5843	1·5812	1·5870	1·5634	1·5793
... ...	1·5717	1·5872	1·5840	1·5869	1·5843	1·5848	1·5702	1·5824
... ...	1·5747	1·5904	1·5870	1·5901	1·5876	1·5905	1·5734	1·5867

he best values from this selection of measurements seem to be:

	α.	β.	γ.	$\gamma-\alpha$.
Li	1·5634	1·5793	1·5843	0·0209
Na	1·5702	1·5824	1·5869	0·0167
Tl	1·5734	1·5867	1·5901	0·0167

Measurements with the optic axial angle apparatus also gave varying resu in different parts of the plates. In one (100) plate the mean value in sodiu light was 2E 85° 11′ (limits 83° 29′–86° 22′), corresponding to $2V_a$ 50° 35′. another (100) plate 2E 85° 48′ (limits 85° 8′–86° 24′). Other measurements wer $2E_{Li}$ 82° 50′, $2E_{Na}$ 83° 31′, $2E_{Tl}$ 84° 29′; $v > r$. A (010) plate measured in oil ga $2H_o$ 144° 25′, corresponding to $2V_o$ 129° 52′ (Na), and $2V_a + 2V_o = 180°\ 27'$.

The chemical analysis of paracelsian made by Miss Hilda Bennett is giv under I (table II) with the molecular proportions under Ia. It agrees close with the formula $BaAl_2Si_2O_8$, analogous to that of anorthite. A spectroscop analysis of paracelsian kindly made in the Research Laboratories of the Gener Electric Company at Wembley showed, in addition to Ba, Al, Si, the presen of traces of Fe, Mn, Cu, Mg, Ca, and B.

Table II. Chemical analyses of paracelsian and celsian.

	I.	Ia.		II.	IIa.		$BaAl_2Si_2O$
SiO_2	33·01	0·5496		32·68	0·5441		32·00
TiO_2...	trace	—		0·08	—		—
Al_2O_3	27·16	0·2664		27·28	0·2676		27·15
Fe_2O_3	0·28	—		0·40	—		—
MnO	trace	—		0·13	—		—
BaO	38·53	0·2512		38·94	0·2539		40·85
SrO	nil	—		nil	—		—
CaO	0·06	0·0011	0·2639	0·08	0·0014	0·2637	100·00
MgO	0·14	0·0035		0·26	0·0065		
Na_2O	0·15	0·0024		nil	—		
K_2O	0·54	0·0057		0·18	0·0019		
SO_3	—	—		0·15			
H_2O+	0·05	—		0·08			
H_2O-	nil	—		0·05			
	99·92			100·31			
Sp. gr.	3·29			3·31			

I. Paracelsian, Benallt mine, Rhiw, Carnarvonshire. Weight used 5 grams. Analyst, Mi Hilda Bennett, 1941. Ia, molecular proportions.

II. Celsian, same locality. Weight used 4 grams. Analyst, Miss Hilda Bennett, 1941. II molecular proportions.

Celsian.

A massive granular rock consists entirely of celsian showing bright cleava surfaces. It is reddish-brown in colour with a somewhat greasy lustre, and speckled and veined with red iron oxide and black manganese oxide. In cavitie there are two distinct habits of crystals:

(1) Larger, stout, short-prismatic crystals of adularia habit, rich in crysta forms, and usually twinned on the Manebach and Baveno laws. The average 1 cm. across, the largest being $1\frac{1}{2}$ cm.

(2) Long, slender to acicular, prisms with few crystal-forms, usually simpl but occasionally twinned on the Carlsbad law. They measure 1–5 mm. i length with a thickness of 0·05–1 mm. Shorter and thicker crystals of th type may show a gradation to smaller crystals of type (1).

The crystals of both kinds are colourless and transparent, but are partl coated with black and white powdery material that can usually be easily rubbe off, while the larger crystals enclose films of iron and manganese oxides. The

r together in the cavities of the rock, and they appear to have grown together
ne same period, though in some cases crystals of habit (2) are deposited on
e of habit (1). While in each cavity there are only a few of the larger twinned
cals (habit 1), the walls of the cavity may be encrusted with thick clusters
icular crystals (habit 2). This association of a few large twinned crystals
a crowd of small slender prisms is similar to that shown by calcite on speci-
s from Egremont in Cumberland and Wheal Wrey in Cornwall. No crystals
aracelsian were found in this celsian-rock. Of the many specimens of para-
an examined only a few showed the presence of celsian crystals of habit 2
e of habit 1) deposited on the paracelsian crystals. Apart from the staining
on and manganese oxides, the only other mineral found on the celsian
imens was one crystal of green baryte.

marked contrast with the crystals of paracelsian, those of celsian always
a prominent *c*(001) cleavage with pearly lustre, and also a less perfect
0) cleavage.

pproximate determinations of the specific gravity were made by floating the
sured crystals in methylene iodide. Crystals of habit 1 gave 3·31–3·33, while
e of habit 2 gave 3·17–3·19. The difference may perhaps be due to attached
rities on the very slender prisms.

veral crystals were measured in many zones on the goniometer, and from
ection of the better readings the following axial ratios were calculated. These
s are compared with previous results obtained on allied minerals:

	Limits.	No.	Mean.
cm(001)(110)	68° 30′–68° 41′	26	68° 37′
co(001)($\bar{1}$11)	54 27 –54 34	15	54 31
oo′($\bar{1}$11)($\bar{1}\bar{1}$1)	53 20 –54 26	6	53 23

	a : *b* : *c*.	*β* (*ac*).
Celsian (Spencer)	0·6613 : 1 : 0·5518	64° 51′
Celsian (Strandmark, 1903)	0·657 : 1 : 0·554	64 58
Hyalophane (Baumhauer, 1903) ...	0·6582 : 1 : 0·5523	64 16
Orthoclase (Koksharov, 1866)	0·6585 : 1 : 0·5554	63 57

ghteen crystal-forms were identified, eleven of which are new for celsian;
most of these correspond to forms already known on orthoclase and hyalo-
ne, and for them Dana's letters for orthoclase have been adopted. The follow-
particulars are given for the three forms not recorded on orthoclase or
ophane.

), small face on five crystals; dull, although adjacent faces are bright. Measured *Jc*
° 35′; *Jb* 73° 17′, 73° 32′; *Jy* (in the zone [*ym*]) 23° 13′, 23° 16′, 23° 28′, 23° 26′ (cal-
ated 23° 13′).

2), long narrow face on the edge *ce*, on two crystals. Measured *Fc* 21° 2′, 21°.

), narrow on edge *eb*, two faces on one crystal. Measured *Gb* 45°, 46°.

addition to the eighteen crystal-forms found on the Welsh crystals, there are
ded in the table of calculated angles (table III) and on the stereographic
ection (fig. 5A) the forms ($\bar{1}$14), ($\bar{3}$11), and ($\bar{3}\bar{3}$1) found by J. E. Strandmark
3) on celsian from Jakobsberg, Sweden, and (310) found by E. Tacconi (1911)
elsian from Candoglia, Piedmont; these are here lettered *U*, *V*, *W*, *Y*,
ectively.

TABLE III. Crystal-forms and calculated angles of celsian.

$a : b : c = 0{\cdot}6613 : 1 : 0{\cdot}5518$, $\beta = 64° 51'$.

Forms.		Angles to: a(100).	b(010).	c(001).
a(100) narrow	... ...	—	90° 0′	64° 51′
b(010) „	... ...	90° 0′	—	90 0
c(001) large...	... ...	64 51	90 0	—
Y(310) (Tacconi)	... ...	11 17	78 43	65 22
m(110) large	... ...	30 54½	59 5½	68 37
L(120) narrow	... ...	50 8	39 52	74 12
z(130) „	... ...	60 53½	29 6½	78 4
x($\bar{1}$01) small	... ...	114 20	90 0	49 29
y($\bar{2}$01) medium	... ...	143 57	90 0	79 6
h(023) small	... ...	66 13	61 35	18 25
n(021) „	... ...	72 30	45 2	44 58
e(111) „	... ...	39 9	72 9	33 46
F(112) narrow	... ...	48 7	78 35	21 2
G(131) „	... ...	54 31	45 59	51 5
U($\bar{1}$14) (Strandmark)	...	76 41	82 21	13 3
g($\bar{1}$12) small	... ...	89 31	74 34	28 49
o($\bar{1}$11) medium	... ...	111 36	63 18½	54 31
s($\bar{1}$31) „	... ...	103 10	33 33	68 58
J($\bar{4}$23) small	... ...	125 29	73 40	63 34
v($\bar{2}$41) medium	... ...	119 33	37 36	88 22
V($\bar{3}$11) (Strandmark)	...	153 33	77 34	91 23
W($\bar{3}$31) „	... ...	139 53	56 32	91 20

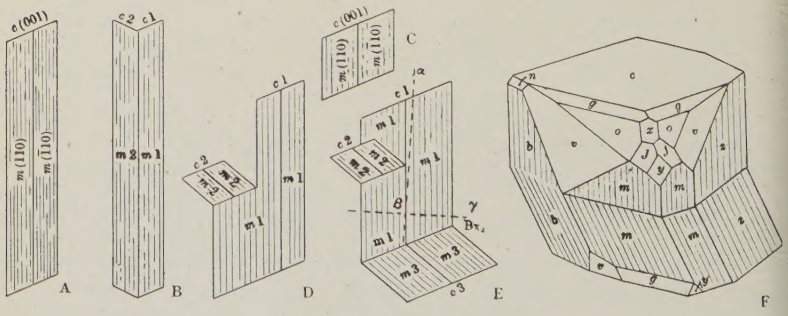

FIG. 3. Celsian crystals from Benallt mine, Carnarvonshire.

A–E, Orthographic projections on (010).

A. Simple crystal of long-prismatic habit.
B. Carlsbad twin of long-prismatic habit.
C. Simple crystal of rhombohedral habit.
D. Manebach twin with unsymmetrical development.
E. Manebach twin with parallel repetition. The optical orientation is indicated in the ma individual.
F. Manebach twin, usual habit, showing many small faces.

The habit of the crystals is controlled by the predominating forms c(001) a m(110). When these are equally developed the habit is pseudo-rhombohedr (fig. 3c), the angles being cm 68° 37′ and mm 61° 49′. A short-prismatic habit, in adularia, is shown in fig. 4A and a long-prismatic habit in fig. 3A. On t larger crystals the edges and corners of these forms are usually replaced by fac

riable size, but usually small, of the common forms $z\,x\,y\,n\,e\,g\,o\,v$. The forms) and b(010) are rarely present as narrow faces in the deeply striated prism . The crystal represented in fig. 3F shows eleven forms; others showed r 15.

anebach twins on (001) are common and of various odd shapes (figs. 3D, E, F; 4B). These combined with Baveno twins on (021) and (0$\bar{2}$1) give fourlings 4D). Similar fourlings could also result by repeated twinning on the Baveno

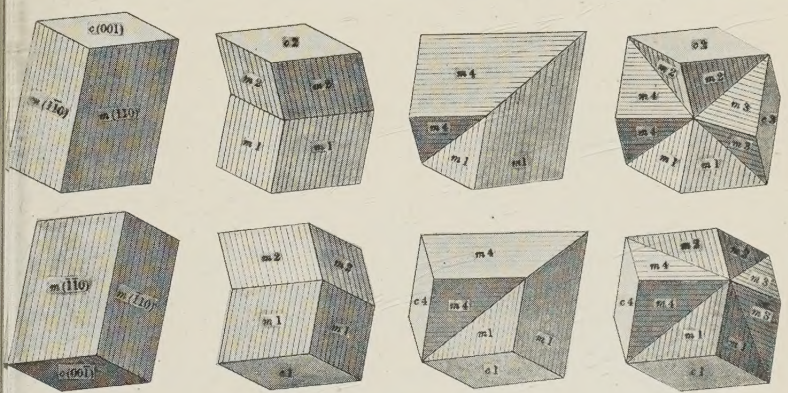

FIG. 4. Celsian crystals from Benallt mine, Carnarvonshire.

Upper row showing front view, lower row showing back view.

imple crystal of short-prismatic habit.

anebach twin of A. Re-entrant angle in front, salient angle at back, $m\bar{m}$ 42° 46′.

aveno twin of A. In front, re-entrant angle $m\bar{m}$ 76° 46′ and salient angle $m\bar{m}$ 12° 5′; at ack, re-entrant angle 12° 5′ and salient angle 76° 46′.

anebach-Baveno fourling. In front, four re-entrant angles of 76° 46′; at the back, four -entrant angles of 12° 5′; all the salient angles between adjacent individuals being cut ut by the overlap.

but, since Manebach twins are here common, it is more natural to regard n as Manebach-Baveno twins. These are illustrated in fig. 4, the upper row ing the front view and the lower row the back. Carlsbad twins were found on the long slender prisms[1] of type 1 (fig. 3B).

ne re-entrant and salient angles at opposite ends of the twinned crystals are:

Manebach	...	...	cm''	111°	23′	$-cm$	68°	37′	$= m\bar{m}$ 42° 46′
Baveno	...	...	nm''	128	23	$-nm$	51	37	$= m\bar{m}$ 76 46
			nm'	96	2	$-nm'''$	83	57	$= m\bar{m}$ 12 5
Carlsbad	...	...	$a'c$	115	9	$-ac$	64	51	$= c\bar{c}$ 50 18

the complete Baveno twin (fig. 4C) there is in front (upper figure) a re- nt angle of 76° 46′ and a salient angle of 12° 5′, and at the back (lower figure) e trant angle of 12° 5′ and a salient angle of 76° 46′. In the fourling (fig. 4D) of these angles are cut out, and there remains in front (upper figure) four t ant angles of 76° 46′ and at the back (lower figure) four re-entrant angles ° 5′. A stereographic projection of this fourling is given in fig. 5B.

. C. Strandmark (1903) on celsian from Jakobsberg, Sweden, mentions that Carlsbad e common, and he found only one each of Manebach and Baveno twins. His drawing arlsbad twin shows an enormously elongated prismatic crystal.

The optical extinction of celsian on (100) is straight, i.e. parallel to the pris edge [001], and the prismatic crystals show negative elongation. The extincti on (010) referred to the same direction is 3° in the acute axial angle β, i.e. $\alpha : c$ $-3°$. Extinction on (001) bisects the angle between the edges *cm*. The op axial plane is in the plane of symmetry and the acute positive bisectrix at 3° the normal to (100) (fig. 3E). Through the front prism edge a good optic pictu is seen in oil with 2V nearly 90° (from approximate measurements without cutti

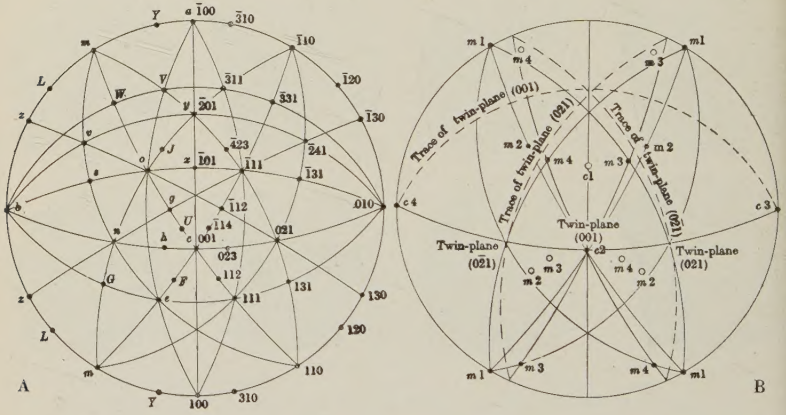

FIG. 5. Stereographic projections of celsian.

A. All the known (22) forms, including *U*, *V*, *W*, *Y* not found on crystals from Wales.
B. Manebach-Baveno fourling.

a plate). Through the perfect cleavage (001) one optic axis emerges obliquel With this optical orientation (which agrees completely with that of Strandma for celsian from Sweden), the refractive indices measured through the natu prism (110)($\bar{1}10$) will be β and very near α. But the results obtained, α' 1·586 β 1·5917 (Na), were not good, owing to the striation of the prism zone. The fi needles show the same optical orientation as the larger crystals. Refracti indices recently determined by Mr. F. A. Bannister by the immersion method a (010) cleavage flake are α 1·580, γ 1·590$\pm$0·003.

The results of Miss Hilda Bennett's analysis of celsian are given under II table II (p. 236). Her first analysis was complicated by the unexpected presen of baryte, a single crystal of which must have been inadvertently includ amongst the cleavage fragments collected. In this material the presence of bar was shown by an X-ray powder photograph taken by Mr. F. A. Bannister. sample submitted to the Research Laboratories of the General Electric Compa at Wembley for spectroscopic analysis showed, in addition to Ba, Al, Si, appre able amounts of Fe and Mn, and traces of Cu, Ni, Sb, Mg, Ca, and B. M Bennett's complete analysis leads to the same formula, $BaAl_2Si_2O_8$, as that giv by her analysis of paracelsian.

X-ray powder photographs of celsian and paracelsian taken by Mr. F. Bannister show different patterns; that of celsian being similar to adularia, wh that of paracelsian is quite distinct. It is hoped that later a more detailed X-

nination may help to solve the perplexing relationship between these rals.

Barium-felspars.

alophane was the first barium-felspar to be recognized and was named by Sartorius von Waltershausen in 1855. It came from the dolomite of the nthal in Switzerland, and had previously been mistaken for adularia, which uch resembles in the monoclinic crystals. Chemical analyses show BaO 5 %, but the crystals are zoned and one analysis shows only 1·84 %. The sition can be expressed as an isomorphous mixture of the orthoclase Si_3O_8) and celsian ($BaAl_2Si_2O_8$) molecules. Hyalophane containing BaO % was later found in the manganese mines at Jakobsberg and Sjögrufvan veden (L. J. Igelström, 1868, 1883, 1888; G. Flink, 1914). Other localities yalophane are Kongsberg in Norway (C. Bugge, 1917), Franklin Furnace ew Jersey (L. H. Bauer and C. Palache, 1926), the Kaso manganese mine in n (T. Yosimura, 1939), and the Slyudyanka river in Siberia (P. V. Kalinin,). Several analyses of orthoclase from various localities have shown the nce of small amounts of barium (A. Mitscherlich, 1860; S. L. Penfield and Sperry, 1888, and others). A tabulation of 329 chemical analyses of potash-ars (orthoclase and microcline) in C. Hintze's 'Handbuch der Mineralogie' 2, 1897) shows the presence of barium (BaO 0·10–3·95 %) in 21 analyses. Strandmark in 1904 proposed to restrict the term hyalophane to members of series from Or_2Cn_1 (BaO 16·4 %) to Or_6Cn_1 (BaO 7·5 %), referring to still r members as barytiferous potash-felspar; and there was a gap in the upper of the series to celsian. A barium-sanidine containing BaO 5 % has been ribed from the Highwood Mountains, Montana (E. S. Larsen and others,).

asoite with BaO 25·50 %, described by T. Yosimura (1936), from the Kaso ganese mine in Japan, now falls in this gap. This author has made an sive study of the barium-felspars. Chemical, optical, and specific gravity collected from the literature, together with many new determinations on nese material, are tabulated and plotted on diagrams. These show a division two groups still with an intervening gap: (1) adularia to hyalophane, and asoite to celsian. In (1) the optical orientation remains that of adularia, the optic axial plane normal to the plane of symmetry (010) and $\gamma - b$.) the optic axial plane lies in (010) with $\beta = b$ and $\alpha : c = -3°$, thus differing the orientation in sanidine. Yosimura points out that several of the ses show a deficiency in silica, and he assumes the presence of the nepheline kaliophilite molecules, Ne = $NaAlSiO_8$ and Kp = $KAlSiO_4$. The presence e se molecules may be the cause of the discontinuity in the plotted curves. of the possible alternatives for the composition of kasoite is given as $Ab_{8·5}, Ne_{9·4}, Kp_{32·5}$.

sian,[1] the end-member of the series, was described by H. Sjögren in 1895 the manganese mines at Jakobsberg, Sweden. From the chemical analysis 9·72 %) he deduced the formula $BaAl_2Si_2O_8$, but from the angles and orientation of cleavage flakes he considered the mineral to be triclinic

[1] Named after the Swedish astronomer Anders Celsius (1701–1744), who devised the Celsius or centigrade thermometer scale.

and a barium-anorthite. Well-developed crystals containing BaO 36·45 % fr the same locality were later described by J. E. Strandmark (1903) and shown be monoclinic. Since then celsian has been recorded from Alaska (BaO 37·7 W. T. Schaller, 1929), California (A. F. Rogers, 1932), and Japan (BaO 34·5 T. Yosimura, 1939).

Paracelsian, of abundant occurrence as grains and granular masses in calciph at Candoglia in Piedmont, was described by E. Tacconi in 1905. From analysis (BaO 34·47 %) he deduced the formula as $Ba_3Al_8Si_8O_{31}$, and from t optical characters (determined in thin sections without any crystal outlines distinct cleavage directions) he considered the mineral to be probably monocli or perhaps triclinic. A careful comparison was made with celsian, and indee new complete chemical analysis (BaO 39·71 %, yielding the formula $BaAl_2Si_2$ and optical determinations were made on material from the original Swed locality. The main difference was in the absence of any distinct cleavage paracelsian; and mention is also made of a difference in specific gravity, pa celsian floating, and celsian sinking, in methylene iodide, although the act difference, 3·325 and 3·37, is not really significant. These are just the points t I noticed in the Welsh crystals. Later, Tacconi (1908, 1911) found a sin minute ($\frac{1}{2}$ mm.) crystal from Candoglia which gave goniometric measureme agreeing with those of Strandmark on celsian from Sweden, and he then admitt that his paracelsian was identical with celsian, although no mention was made any cleavage. In this conclusion he appears to have been unduly influenced Strandmark's paper, which apparently he had not previously seen. It is m probable that at Candoglia, as at the Welsh locality, both celsian and paracelsi occur together. Tacconi makes no mention of any lamellar twinning in pa celsian. In the Welsh crystals this was only faintly seen when the sections w near the position of optical extinction. His angle of 92° between indistin cleavages perhaps corresponds to my angle 93° 7′ between the variable prisma cleavage. His optic axial angle 2V 82° 33′–84° 44′ is near to my value 2E 83° 2 86° 22′, suggesting possibly a misprint.

In the plagioclase-felspars barium is much less frequently present. In a tabu tion of 637 chemical analyses of plagioclases in C. Hintze's 'Handbuch Mineralogie' (vol. 2, 1897) barium appears only once, in an andesine fr Bodenmais, Bavaria, with BaO 0·24 %. In 30 analyses of K-Na-felspars (anort clase) none shows any barium. A barium-plagioclase containing BaO 7·30 was described from an unknown locality by A. Des Cloizeaux in 1877; and containing BaO 5·7 % from Broken Hill, New South Wales, by S. R. Nocko and E. G. Zies in 1933. A 'barium-albite' is mentioned by T. Yosimura (19 p. 385) as an impurity in mangan-hedenbergite from the Kaso mine, Japan, analysis of which shows BaO 1·28 %, and the composition of the felspar calculated as $Ab_{44}An_{42}Cn_{14}$.

Artificial barium-felspar, $BaAl_2Si_2O_8$, has been prepared by different work but with varying results. The earliest experiments were by F. Fouqué A. Michel-Lévy (1880), who by fusing a mixture of the oxides obtained microli which were apparently orthorhombic and free from twinning. E. Dittler (19 by simple fusion obtained plates, also apparently orthorhombic and free fr twinning. A. S. Ginzberg (1915) prepared mixed triclinic crystals of anort containing up to 20 % $BaAl_2Si_2O_8$, the excess of $BaAl_2Si_2O_8$ crystallizing

gonal plates which were optically uniaxial with positive sign and called um-nepheline'.[1] Hexagonal mixed crystals containing 15 % $KAlSi_3O_8$ also obtained. P. Eskola (1922) using a barium vanadate flux also obtained rently orthorhombic crystals, but in reality these were Carlsbad twins with al characters agreeing with those of natural celsian. E. Dittler and asch (1930, 1931) obtained hexagonal plates of $BaAl_2Si_2O_8$ up to 10 mm. ss, which were optically uniaxial with negative sign; this was called lsian', and similar but smaller mixed crystals containing up to 30% $KAlSi_3O_8$ also obtained. 'α-Celsian' has been recorded from a lead slag (W. Faber,).

Bibliography of Barium-felspars.

ER (L. H.) and Palache (C.). Hyalophane from Franklin Furnace, New Jersey. Amer. Min., 1926, vol. 11, pp. 172–174. [M.A. 3–312.]

HAUER (H.). Beitrag zur Kenntniss des Hyalophan. Zeits. Kryst. Min., 1903, vol. 37, pp. 603–608.

E (C.). Kongsbergfeltets geologi. Norges Geol. Undersök., 1917, no. 82, p. 145. (Hyalophane from Kongsberg, Norway, BaO 8·80%.)

Cloizeaux (A.). Ein neuer Barytfeldspath. Min. Mitt. (Tschermak), 1877, pp. 99–100. Note sur un nouveau feldspath barytique. Bull. Soc. Min. France, 1878, vol. 1, pp. 84–86.

ER (E.). Ueber das Verhalten des Orthoklas zu Andesin und Celsian und über seine Stabilität in künstlichen Schmelzen. Min. Petr. Mitt. (Tschermak), 1911, vol. 30, pp. 118–127.

and Lasch (H.). Synthetische Untersuchungen über die Mischkristallbildung des Barium- und Strontiumfeldspates mit Orthoklas. Anzeiger Akad. Wiss. Wien, Math.-naturwiss. Kl., 1930, vol. 67, pp. 201–203. [M.A. 5–102.]

—— Neue synthetische Untersuchungen in der Feldspatgruppe. Sitz.-ber. Akad. Wiss. Wien, Math.-naturwiss. Kl., Abt. I, 1931, vol. 140, pp. 633–674. [M.A. 5–102.]

LA (P.). The silicates of strontium and barium. Amer. Journ. Sci., 1922, ser. 5, vol. 4, pp. 331–375. [M.A. 2–153.]

R (W.). Die Mineralien der Bleischlacken. Chemie der Erde, 1935, vol. 10, pp. 67–115. α-Celsian in slag, p. 85.) [M.A. 6–355.]

K (G.). Bidrag till Sveriges mineralogi, 3. Arch. Kemi, Min. Geol., 1914, vol. 5, no. 10. Optical determinations by V. M. Goldschmidt and chemical analysis by N. Sahlbom of hyalophane from Sjögrufvan, p. 101; celsian from Jakobsberg, p. 117.)

UÉ (F.) and Michel-Lévy (A.). Sur la production artificielle de feldspaths à base de baryte, de strontiane et de plomb, correspondant à l'oligoclase, au labrador et à l'anorthit; étude des propriétés optiques de ces minéraux. Bull. Soc. Min. France, 1880, vol. 3, pp. 124–128.

—— Synthèse des minéraux et des roches. Paris, 1882, p. 145.

BERG (A. S.). О нѣкоторыхъ искусственныхъ барiевыхъ алюмосиликатахъ. [On some artificial barium alumosilicates.] Ann. Inst. Polytechn. Pétrograde, 1915, vol. 23. [M.A. 2–153.]

STRÖM (L. J.). Sällsynta och nya mineralier från Vermland: . . . och hyalophan. Öfvers. K. Vetenskaps-Akad. Förh. Stockholm, 1868, vol. 24 (for 1867), pp. 11–16.

—— Hyalophane bleu-verdâtre de Jakobsberg (Wermland) Suède. Bull. Soc. Min. France, 1883, vol. 6, pp. 139–142.

—— Mineralogiska meddelanden. 6. Baryt-fältspater från Sjögrufvefältet. Geol. För. Förh. Stockholm, 1888, vol. 10, pp. 416–417. Translation: Feldspaths barytiques des mines de manganèse de Söjgrufvan [*sic*], paroisse de Grythyttan, gouvernement d'Örebro, Suède. Bull. Soc. Franç. Min., 1888, vol. 11, pp. 263–264.

NOV (P. V.). Hyalophane from the Slyudyanka river. Compt. Rend. (Doklady) Acad. Sci. URSS, 1939, vol. 23, pp. 163–164. [M.A. 7–444].

his high-temperature hexagonal modification of $BaAl_2Si_2O_8$ had been previously ned by Z. Weyberg (1904) by fusing kaolin with $BaCl_2$.

Larsen (E. S.), Hurlbut (C. S.), Buie (B. F.), and Burgess (C. H.). Igneous rocks of Highwood Mountains, Montana. Part VI, Mineralogy. Bull. Geol. Soc. Amer., 1941, v 52, pp. 1841–1856. (Barium-sanidine, p. 1849.)

Meier (A. E.). Association of harmotome and barium feldspar at Glen Riddle, Pennsylvan Amer. Min., 1939, vol. 24, pp. 540–560.

Mitscherlich (A.). Beiträge zur analytischen Chemie. V. Auffindung von Baryterde Feldspath. Ann. Phys. Chem. (Poggendorff), 1860, vol. 81, pp. 113–114.

Nockolds (S. R.) and Zies (E. G.). On a new barium plagioclase felspar. Min. Mag., 19 vol. 23, pp. 448–457.

Obermayer (F.). Morphologische Studien an Hyalophan und Labradorit. Zeits. Kry Min., 1883, vol. 7, pp. 64–68.

Penfield (S. L.) and Sperry (E. S.). Mineralogical notes. 7. Barium feldspar from Blue H Delaware Co., Pa.; the cassinite of Dr. I. Lea. Amer. Journ. Sci., 1888, ser. 3, vol. pp. 326–329.

Petersen (T.). Zur Kenntnis der Mineralien des Binnenthales, Kanton Wallis, Schwe Ber. Offenbacher Ver. Naturk., 1866, vol. 7, pp. 128 132. (Analysis of hyalophan [Abstract, Neues Jahrb. Min., 1867, p. 102.]

Rinne (F.). Ueber Hyalophan aus dem Binnenthale (Wallis). Neues Jahrb. Min., 1884, v 1, pp. 206–215.

Rogers (A. F.). Sanbornite, a new barium silicate mineral from Mariposa County, Californ Amer. Min., 1932, vol. 17, pp. 161 -172. (With celsian as minute grains, p. 171.) [M.A. 145.]

Russell (A.). An occurrence of the barium-felspar celsian in north Wales. Nature, Lond 1911, vol. 86, p. 180.

Sandberger (F. von). Hyalophan auf Klüften des Buntsandsteins am Steinberg bei Wald unweit Furtwangen [Baden]. Neues Jahrb. Min., 1892, vol. 1, pp. 67–68.

Sartorius von Waltershausen (W.). [Mineralogical notes.] Sitz.-ber. Akad. Wiss. Wi Math.-naturwiss. Cl., 1855, vol. 14 (for 1854), pp. 290 292. (Hyalophane from Bir p. 292.)

—— Ein Beitrag zur näheren Kenntniss des Dolomits in den Walliser Alpen. Ann. Ph Chem. (Poggendorff), 1855, vol. 94, pp. 115 141. (Hyalophane, pp. 134–136.)

—— Ibid., 1857, vol. 100, pp. 537–550. (Hyalophane, pp. 547–549.)

Schaller (W. T.). The properties and associated minerals of gillespite [2BaO.2FeO.8Si from Alaska]. Amer. Min., 1929, vol. 14, pp. 319–322. (Celsian, p. 321.) [M.A. 4–237.]

Schiebold (E.). Über den Feinbau der Feldspate. Fortschr. Min. Krist. Petr., 1927, vol. pp. 78 82; Centralblatt Min., Abt. A, 1927, pp. 453–458; Zeits. Krist., 1928, vol. pp. 488–493. (X-ray data for hyalophane.) [M.A. 4–31.]

—— Über die Isomorphie der Feldspatmineralien. Neues Jahrb. Min., Abt. A, 1931, Bei Bd. 64, pp. 251–320. [M.A. 6–61.]

Sjögren (H.). Celsian, en anorthiten motsvarande bariumfältspat från Jakobsberg. Ge För. Förh. Stockholm, 1895, vol. 17, pp. 578–582. [Min. Mag. 11–325.]

Solly (R. H.). On various minerals (anatase, &c.), from the Binnenthal. Min. Mag., 19 vol. 14, pp. 16–17; 1906, vol. 14, p. 190.

Stockar-Escher (—). Kenngott's Uebers. Min. Forsch., 1859, for 1856–57, p. 157. (Analy of hyalophane from Binn.)

Strandmark (J. E.). Bidrag till kännedomen om celsian och andra baryt-fältspater. Celsian. Geol. För. Förh. Stockholm, 1903, vol. 25, pp. 289–318. II. Baryt-kalifältspat Ibid., 1904, vol. 26, pp. 97–133. Separates as Inaug.-Diss. Univ. Lund, 1904. [Abstra Zeits. Kryst. Min., 1907, vol. 43, pp. 89–92.]

Tacconi (E.). Di un silicato di alluminio e bario [paracelsian] dei calcefiri di Candoglia valle del Toce. Rend. R. Ist. Lombardo Sci. Lett. Milano, 1905, ser. 2, vol. 38, pp. 63 643. [Min. Mag. 14–406.]

—— Taramellite, nuovo silicato di ferro e bario. Rend. Accad. Lincei, Cl. sci. fis. mat. na Roma, 1908, ser. 5, vol. 17, sem. 1, pp. 810–814. (Footnote on p. 811 mentions that goni metric measurements of a minute crystal of 'paracelsian' agree with celsian.)

—— La massa calcare ed i calcefiri di Candoglia in valle del Toce. Atti Soc. Ital. Sci. Na Milano, 1911, vol. 50, pp. 55–94. (Celsian, p. 64.)

Taylor (W. H.), Darbyshire (J. A.), and Strunz (H.). An X-ray investigation of t

elspars. Zeits. Krist., 1934, vol. 87, pp. 464–498. (X-ray data for hyalophane and elsian, p. 471.) [M.A. **6**–177.]

BERG (Z.). О баріевомъ и стронціевомъ нефелинѣ. [On barium and strontium nephelines.] Bull. Univ. Varsovie, 1904, vol. 4, pp. 1–5; Trav. Soc. Nat. Varsovie, Compt. Rend. Sect. Phys. Chim., 1906, vols. 14–15 (for 1903–04), pp. 1–5.

Ueber die Wirkung von Baryumchlorid und Strontiumchlorid auf Kaolin bei hoher Temperatur. Centralblatt Min., 1905, pp. 138–142.

WELL (A. N.). Studies in the feldspar group. Journ. Geol. Chicago, 1925, vol. 33, pp. 714–727. (K–Ba series, pp. 724–725.) [M.A. **3**–78.]

Elements of optical mineralogy. 3rd edit., 1933, pt. 2, p. 354. (Reproducing the K-Ba-elspar diagram.)

URA (Toyohumi) formerly YOSHIMURA (Toyofumi). On barium felspars from the Kaso mine, Tochigi prefecture, Japan. (Japanese.) Journ. Geol. Soc. Japan, 1936, vol. 43, pp. 877–910. [M.A. **6**–489.]

Studies on the minerals from the manganese deposit of the Kaso mine, Japan. Journ. Fac. Sci. Hokkaido Univ., Ser. 4, 1939, vol. 4, pp. 313–451. (Barium-felspars, pp. 364–385.) [M.A. **7**–412.]

An analysis of the movements of shadow-edges on the refractometer in the case of biaxial gemstones.

By E. J. Burbage and B. W. Anderson.

[Read March 19, 1942.]

THE study and identification of the gem minerals present difficulties which a not to be resolved by the ordinary methods of mineralogy. The commerc value of the material forbids recourse to chemical reagents and the blowpi and when faceted and mounted, the criteria of crystal form and specific gravi are also inapplicable. Optical phenomena then constitute the sole means discrimination, and the refractometer, spectroscope, polariscope, and dichrosco become the only arbiters between gemstones of similar appearance but differe species. The function of the polariscope is to narrow the field of inquiry differentiating between isotropic and anisotropic gemstones; the verdict of t spectroscope is unequivocal in gemstones characterized by absorption spect which, unfortunately, form a minority; dichroism, when present, can be regard as supplementary evidence only; the refractometer, an instrument of wi application than the spectroscope, and capable of yielding information which usually equally unambiguous, thus assumes a role of primary importance. T method of minimum deviation, while furnishing refractive index readings whi are far more critical, is attended by difficulties which outweigh this advanta since gem material in the rough is usually too valuable to be ground into prisms, and after it has passed through the lapidary's hands is seldom found have a pair of facets which are sufficiently plane and suitably inclined to employed for this purpose. Moreover, the accuracy of spectrometric refracti index determinations is largely nullified when, as in anisotropic faceted ge stones, optical orientation is difficult or impossible to establish, whereas with t refractometer, maximum and minimum readings are obtainable from any fac provided these values lie within the range of the instrument. For ordin identification purposes it is sufficient when using the refractometer to comb a reasonable degree of manipulative skill with a knowledge of this fact, ignor the apparently fortuitous behaviour of the shadow-edges in their moveme between the two limiting values. However, a theoretical explanation of shadow-edge movements is essential when anything beyond an everyday rout use of the instrument is proposed, and it is intended in the present paper describe techniques employing the methods of analytical geometry by wh these movements can be investigated. Some points of practical importa which are relevant to this analysis will also be discussed.

The theory of the refractometer postulates a hemisphere or prism which optically denser than the stone whose refractive indices it is desired to read.

earlier forms of the instrument,[1] the dense-glass hemisphere had a refractive x lower than those of several important gemstones, which were in consequence ond its range, but in later models[2] a greater range has been provided by the loyment of types of glass having very high refractive indices, and, still more tly,[3] isotropic crystalline materials have been used still further to extend range. Another practical difficulty of a similar kind arises from the necessity fecting optical contact between the stone and the hemisphere by means of quid of high refractive index, but here again recent years have seen the oduction of new liquids for this purpose, which have effectively widened the e of the instrument.[3]

or the identification of precious stones, the primary function of refractometers his type, no very exacting standards of accuracy are ordinarily required, and erance of $\pm 0{\cdot}005$ is usually permissible. For an experienced observer, using ecially calibrated instrument, the limits consistently possible are approxi- ly $\pm 0{\cdot}001$. Data of this kind would be hopelessly inadequate for the purpose e present analysis, and their development from empirically determined results mpossible. It has therefore been developed theoretically from an initial ideration of the fundamental principle common to all types of the instrument available. Reference to any extended applications of the refractometer ested by an analysis of this kind would need a full discussion of the possi- es and limitations of the instrument, a discussion which is beyond the scope e present paper, and the only incursion into this field which has been included at of the determination of β in biaxial gemstones. It is probable that, given nstrument of a precision character, such as the Abbe-Zeiss, the absence of rvational crudities would justify further research, and that it might be ble, for instance, to develop a technique for the ascertainment of the optical ntation of any facet of a gemstone from a set of refractive index readings ed from it. Further to pursue these interesting possibilities also lies beyond scope of the present inquiry.

refractive index reading, or pair of readings, obtained from a facet of a tone on the refractometer, corresponds to a direction at right angles to the al to that facet. In the Tully refractometer, the hemisphere can be rotated ve values corresponding to all directions at right angles to this normal, and her models with a fixed stage, the stone itself can be rotated with the same t. In terms of the optical indicatrix, the refractive indices for any direction gh a crystalline medium are graphically represented by the lengths of the -axes of the ellipse formed by the intersection of the indicatrix and that through its centre which has this direction as normal. Thus the values in a rotation through two right angles of a gemstone are represented by emi-axes of the ellipses formed by a family of planes passing through the e of the indicatrix and sharing a common line of intersection, which is ormal to the facet being employed.

on this basis it is possible, given the values of the principal axes of the ix, and the optical orientation of the normal to the facet, to calculate all fractive indices which will be obtained during the complete rotation of the

1. H. Herbert Smith, Min. Mag., 1905, vol. 14, pp. 83-86; 1907, vol. 14, pp. 354-359.
2. E. Tully, ibid., 1927, vol. 21, pp. 324-328.
3. W. Anderson, C. J. Payne, and J. Pike, ibid., 1940, vol. 25, pp. 579-583.

stone on the refractometer. For this purpose it is useful to consider the questic as a problem in analytical geometry, using the conventions and terminology that subject, rather than those of mineralogy.[1]

The semi-axes of the ellipses formed by the intersection of any plane with a ellipsoid are given by the following expression:

$$\frac{a^2l^2}{a^2-r^2}+\frac{b^2m^2}{b^2-r^2}+\frac{c^2n^2}{c^2-r^2}=0. \quad \ldots \quad \ldots \quad \ldots \quad (i)$$

This equation is a biquadratic in r; l, m, and n, and a, b, and c have the usual significances as direction-cosines of the plane, and the principal semi-ax of the ellipsoid, respectively. Applying to it the familiar rule for the solution quadratic equations, two roots in r^2 are given, the square roots of which are tl required values of the semi-axes. (An alternative and less clumsy method solution is obtainable by manipulating the expressions for the sum and produ of the roots.) To obtain values of the direction-cosines for successive positio during the rotation in terms of those of the normal to the facet, the latter written in the form of the intersection of two planes L and L_1. Then $L+\lambda L_1$ the equation of a plane having a common line of intersection with these two plane and by giving lambda all possible values, the equations of all planes intersecti in the normal to the facet are obtained. Writing down the equations of a sufficie number of these planes, the angles between which are given by the relationsh $ll_1+mm_1+nn_1=\cos\theta$, and using equation (i) to calculate the correspondi refractive index values, the necessary data are obtained for the constructic of curves graphically representing the movements of the shadow-edges seen c the refractometer scale during a complete rotation.

A specific instance may be given in illustration. A set of principal values f a topaz from Minas Geraes has been recorded as α 1·6294, β 1·6308, and γ 1·637 and may be regarded as sufficiently typical for this mineral. A gemstone is c from this material, and refractive index readings are made on the refractomete using for this purpose the table facet, which happens to be equally inclined each of the principal optical directions. It is required to construct a pair curves showing the variation in these readings during a rotation with or on t refractometer stage. The equation of the normal to the facet may be writte as $x=y=z$, or, choosing one of the infinitely many ways of writing th straight line in the form of the intersection of two planes, as

$$\left.\begin{aligned}3x-2y-z&=0\\ x+y-2z&=0\end{aligned}\right\}.$$

The equations of the planes which intersect in this straight line are of the form

$$3x-2y-z+\lambda(x+y-2z)=0. \quad \ldots \quad \ldots \quad \ldots \quad (i$$

[1] When algebraic methods are used to investigate the behaviour of anisotropic gemstor on the refractometer, the retention of the symbols a, b, and c of the ellipsoid is justified on t ground of consistency, since those for the direction-cosines are lower-case members of the sa alphabet. When the results are used to interpret biaxial phenomena, a, b, and c are equated α, β, and γ respectively. Mathematically, an analysis of the properties of uniaxal miner follows similar lines, the appropriate modification being introduced that two of the princi semi-axes are equal in length, and the final results are restated in terms of the omega a epsilon of mineralogy.

n equation (i) the following results are obtained:

$$r_1^2+r_{11}^2 = \frac{a^2l^2(b^2+c^2)+b^2m^2(a^2+c^2)+c^2n^2(a^2+b^2)}{a^2l^2+b^2m^2+c^2n^2}$$

$$r_1^2 r_{11}^2 = \frac{a^2b^2c^2}{a^2l^2+b^2m^2+c^2n^2}.$$

ting $\lambda = 0$ in equation (ii), which then becomes $3x-2y-z = 0$, it is ble, on inserting the values of a, b, c, l, m, and n in the equations written e. to calculate r_1 and r_{11}, which prove to be 1·6304 and 1·6370. Similarly = 1, equation (ii) becomes $4x-y-3z = 0$, and the refractive indices are 075 and 1·6347. The angle between this plane and that for $\lambda = 0$ is 27°. eating this process, taking a number of values of λ, selected at random, choosing the plane for $\lambda = 0$ as giving the initial point from which degrees tation are measured, these results are obtained:

λ.	Angle from $\lambda = 0$.	Equation.	r_1.	r_{11}.
0	0°	$3x-2y-z = 0$	1·6304	1·6370
1	27	$4x-y-3z = 0$	1·63075	1·6347
2	40 54′	$x-z = 0$	1·6308	1·6334
6	58 17	$9x+4y-13z = 0$	1·6305	1·63255
∞	70 54	$x+y-2z = 0$	1·6300	1·6327
$-\frac{1}{2}$	−19 6	$x-y = 0$	1·6301	1·6375
−1	−38 14	$2x-3y+z = 0$	1·6300	1·6368
−2	−65 14	$x-4y+3z = 0$	1·6295	1·6352
−3	−79 8	$y-z = 0$	1·6294	1·63405

n these figures the curves shown in fig. 1 can then be plotted.

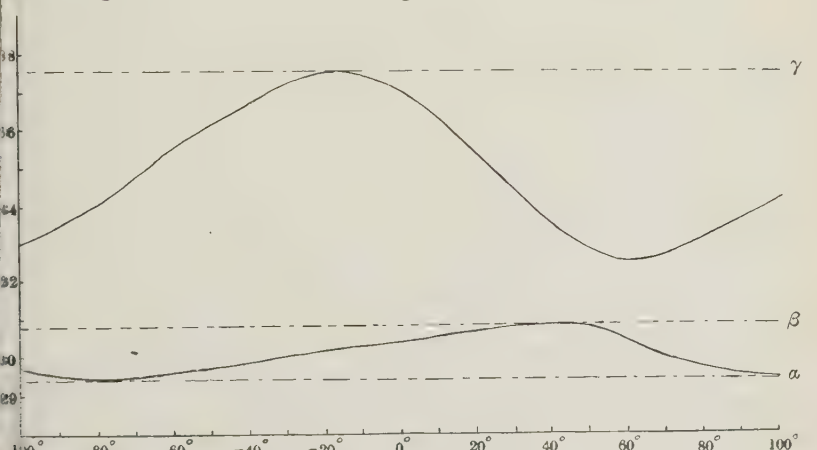

Fig. 1. Curves of refractometer shadow-edges on a facet of topaz.

n ay be noted that the ordinates of this graph are evenly spaced, whereas ii isions of the scale of the refractometer become increasingly widely spaced crease in refractive index. It is easily seen that this compression of the ometer scale at the 'low' end is imposed by the fundamental principle

of the instrument; it can be verified that the spacing is a function of the cotange of the critical angle. Fortunately, there are few gemstones having refracti indices less than 1·5, so that in practice this tends to be an advantage rath than a demerit, permitting greater accuracy in the region where it is of mo use. In the graphs of shadow-edge curves accompanying this paper, it would pointless to mirror this practical exigency, which is therefore ignored. It scarcely necessary to add that fourth-figure accuracy, which is easily attainab in the calculated values employed for the construction of these curves, is u fortunately impossible of achievement in practice, except with the more elabora and costly total reflectometers of the Abbe or Pulfrich type.

There are four turning-points in a typical pair of biaxial shadow-edge curve three of which are coincident with the principal values for the mineral und examination. These are the a, b, and c of the ellipsoid, or, in mineralogic terms, α, β, and γ. The analysis makes it evident that any facet of a biaxi gemstone must give readings of α, β, and γ during a rotation through two rig angles.[1] It has been seen that the equation of the normal to the facet may written in the form of the joint equation of two planes L and L_1, and it will evident that, whatever the coefficients of x, y, and z in these two planes, it always possible to find a plane passing through their intersection in whos equation the x-term is missing. This is effected by assigning a suitable valu to λ in $L+\lambda L_1$, the equation representing the pencil of planes intersecting the normal to the facet. For example, when $\lambda = -3$, equation (ii) reduces $y-z = 0$. All such planes whose equations lack an x-term intersect in the x-axi and hence in their intersection with the ellipsoid form ellipses all of which sha a common axis, of length $2a$.[2] Thus at one point during the rotation of an biaxial gemstone on the refractometer, a reading of α must be given, and, b a similar reasoning, readings of β and γ are also furnished.

Being maxima and minima, the turning-points at γ and α are immediate recognizable, but to distinguish between β and the fourth turning-point is le simple. As has been pointed out by Dr. Herbert Smith ('Gemstones.' Londo 1940, p. 54 et seq.), a comparison of results obtained from two non-paral facets will enable this distinction to be made, β being that median turnin point which will be common to both. If this is impracticable, as in the case most mounted gemstones, it is possible to calculate β from data provided readings from one facet only, and a formula for this purpose may be give When the stone on the stage of the refractometer has been rotated into t position giving the maximum reading γ, the other shadow-edge provides second reading, and similarly there is an associated value seen when one ed is at the α position. Calling these associated readings R and r, and the ang between the points at which they occur ϕ, an approximation to the value of β given by the following expression:

$$\cos^2\phi = \frac{\alpha^2\gamma^2}{r^2R^2}\cdot\frac{(\beta^2-r^2)(\beta^2-R^2)}{(\beta^2-\alpha^2)(\beta^2-\gamma^2)}. \quad \ldots \quad \ldots \quad \ldots \quad ($$

It will be seen that this method does not require considerations of the values

[1] L. J. Spencer, Gemmologist, London, 1937, vol. 6, pp. 231–236.

[2] This can be checked by rewriting equation (i) as a straightforward biquadratic, equatin to zero, and showing that the resultant equation has a root $r^2 = a^2$ by the factor theorem.

median turning-points to be taken into account, but it is clear that a check forded by comparison with the appropriate value.

nother criterion by which β can be separated from the second median point ses when the Herbert Smith test is inapplicable is furnished by observation e behaviour of the shadow-edges when a polarizing filter is employed. Such s are commercially available for one type of instrument, in the form of a cap the eyepiece, but an accessory of this kind can be improvised without culty for use with any refractometer. When, in a doubly-refractive stone, sufficient separation of the shadow-edges makes critical readings difficult, it eful to make separate observations of each edge by extinguishing the other neans of a polarizing cap. This is rotated into a position which is visually ed to effect optimum extinction of the unwanted shadow-edge, a position h is variable for a biaxial stone and constant for a uniaxial—an effect which nalogous to the behaviour of minerals in thin section between the crossed ls of a petrological microscope. In terms of the indicatrix, it will be apparent , for successive positions during the rotation of a biaxial stone, the corre- ding ellipses of section will in general have their axes occupying skew posi- s with regard to the principal optical directions; the skew directions will be cident with the positions of maximum extinction. Straight extinction with ect to the principal optical directions is shown at positions in which a princi- value (α, β, or γ) is given. For a uniaxial stone, the indicatrix becomes a rroid, and the directions of maximum extinction are invariant.

ence a way of discriminating between β and the other median turning-point fforded by the following means: the stone is placed in a position to give ading of α, and the polarizing cap is adjusted to extinguish the shadow-edge ng this reading. The stone is then rotated into the position giving the lower ian turning-point reading, and the angle through which the polarizing cap to be rotated to extinguish this reading is noted. A similar procedure is wed to find the angle of rotation of the polarizing cap between the γ position that affording the upper median turning-point. The angle of rotation of the for the median turning-point which is not β will differ from that which is, eing sensibly different from zero.

his second method of obtaining β from readings given by one facet of a biaxial stone is simpler in practice and theoretically preferable to the first, since the ee of error in a calculated result based upon a set of five observations which not be critically accurate is likely to be high. An example may be given in tration. A step-cut peridot from the Congo gave these readings: α 1·643, iated value 1·665; γ 1·681, associated value 1·650; angular distance between positions giving these readings, 15°. The calculated value of β given by ula (iii) is 1·657—probably somewhat too low. The other method, which ls the tedium of arithmetical calculations, has proved to be fairly satisfactory ractice. Observations from a random set of eight gemstones yielded the wing results: in five cases (two peridots, two topazes, and a hambergite), the was applicable, and its correctness was confirmed; three other stones gave conclusive results (a peridot required no appreciable shift in position of the ri ing cap for extinction at either median turning-point, and in a peridot a diopside the extinction positions were not determinable with sufficient ra y).

The degree of rotation of the polarizing cap for the extinction of a shadov edge is a function of the orientation of the normal-to-facet position with respe to the principal optical directions of the stone. If the direction-cosines of t axes of the ellipse formed by the intersection of the plane $lx+my+nz = 0$ an the ellipsoid $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2} = 1$ are λ_1, μ_1, and ν_1, and λ_{11}, μ_{11}, and ν_{11}, then the ratios are expressible as follows:

$$\lambda_1\left(\frac{a^2-r^2}{a^2l}\right) = \mu_1\left(\frac{b^2-r^2}{b^2m}\right) = \nu_1\left(\frac{c^2-r^2}{c^2n}\right), \quad \ldots \quad \ldots \quad \text{(i}$$

and similarly for λ_{11}, μ_{11}, and ν_{11}. After the determination of their directio cosines, the angles which these axes make with the principal axes are calculabl and hence also the degree of rotation of the polarizing cap necessary for extinctio when one of these directions is selected as the initial position.

If the selected facet of a biaxial gemstone has its normal coincident with principal optical direction, the refractive index curves assume special forms each of which one of the shadow-edges traces out a straight line. In practi these 'special' cases occur with an unexpected frequency, and therefore mer separate consideration.

(i) When the normal to the facet is coincident with X, one shadow-edge mov between β and γ, and the other remains constant at α.

(ii) Normal to facet coincident with Y, one shadow-edge remains constant at the other moves between α and γ, and thus coalesces with the stationary shadow edge at two points.

(iii) Normal to facet coincident with Z, one shadow-edge remains consta at γ, and the other moves between α and β.

In fig. 2 the shadow-edge curves for these 'special' orientations are sketche A partial explanation of the relative frequency with which these 'special' cas are encountered is to be found in the lapidary's choice of a principal optic direction as the symmetry axis of the stone, to take advantage of the habit the crystal, to display colour to best advantage, or to utilize a cleavage tren For this reason, an additional case in which coalescence of the shadow-edges β takes place is much more infrequent ; it occurs when, in a gemstone whose cuttin is not specially related to its principal optical directions, the median turnin points are coincident. The degree of probability is low that, for a line chosen random through the centre of an ellipsoid, the pencil of planes intersecting this line should include one cutting the ellipsoid in a circular section, and he unlike the other cases discussed in which coalescence at β occurs, chance operat to the exclusion of choice. In practice a simulation of this behaviour may resu from the impossibility of obtaining sufficiently critical readings to differentia between readings showing a separation of the order of 0·001. This may be illu trated by reference to fig. 1. Here a minimum separation of about 0·002 occu a degree of birefringence which might be overlooked on casual scrutiny of t stone on the refractometer. This might appear to indicate a close approach an optical axial position, but in point of fact the angular distance between t plane giving this minimum birefringence and the nearest optic axial plane about 16°. It seems reasonable to infer that cases in which apparent coalescen of this kind occurs are not infrequent.

inally, reference must be made to the forms assumed by the shadow-edge ves of isotropic and uniaxial gemstones. The straight line traced out by the ionary shadow-edge of an isotropic medium calls for no comment. An

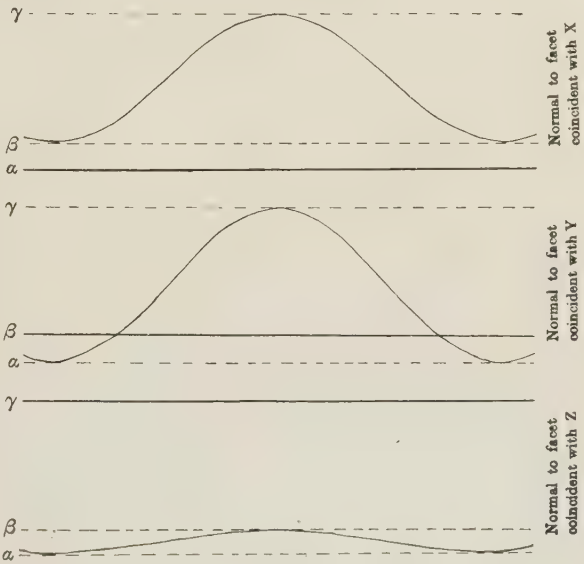

Fig. 2. Curves of refractometer shadow-edges on the three principal planes of a biaxial crystal.

ysis of the behaviour of the uniaxial division can follow similar lines to that ribed earlier in this paper, when a more general case was considered, the ssary modification being introduced that the maximum or minimum principal active index shall be coincident with the intermediate principal refractive x. It will be evident that the shadow-edge curves traced out assume the forms straight line, given by the refractive index ω, and a curve sweeping between line and a maximum or minimum at ϵ. These curves are sketched in fig. 3.

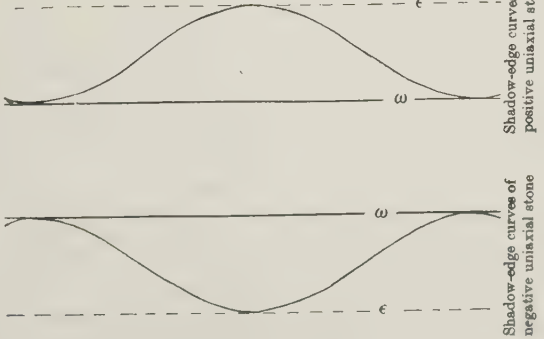

Fig. 3. Curves of refractometer shadow-edges of uniaxial crystals.

Cummingtonite and gedrite from Sutherland.

By R. S. Collins, Ph.D., B.Sc., F.G.S.

Department of Geology, Imperial College of Science and Technology, London

[Read January 22, 1942.]

I. *Introduction.*

During the investigation of a migmatite complex near Strathy, nort Sutherland, cummingtonite and gedrite were found to be common co stituents of certain schists and granulites. Calcium-poor amphiboles have n hitherto been recorded from rocks of the Moine Series, and it is the purpose this paper to give the results of the optical and chemical study of three exampl of this group. The methods of separation and purification employed are describe in some detail as it is considered that many of the previous analyses of the minerals are vitiated by faulty procedure. To avoid errors in separating tw amphibole species, the investigated samples were taken from rocks containi a single amphibole phase. The paper concludes with a discussion of the correl tion of optical properties and chemical composition of cummingtonites a gedrites.

II. *Methods of separation and purification.*

The fresh rock wrapped in layers of filter-paper was hammered down to fra ments the size of a pea, which were transferred to an agate mortar and grou down until the powder passed through 60 and 120 mesh sieves. Centrifugati using bromoform floated off the quartz, the felspar, and some biotite. Iron-o garnet, and rutile were removed as a heavy crop by centrifugation with methyle iodide. The fraction obtained from twenty-four centrifugations still contain some biotite, which was removed mainly by using a carefully adjusted mixtu of methylene iodide and benzene which just floated biotite. A 99·5 % pu sample resulted. Repeated panning on large sheets of filter-paper remov almost all the remaining biotite. There resulted an even-grained powder whi was hand-picked on a hard white card using an × 8 pocket-lens. The da cummingtonite sample contained some quartz-magnetite composite grains whi defied gravity separation and were too numerous for hand-picking. The samp was ground down finer in a diamond mortar and the complex grains disintegrat The quartz and magnetite were removed by bromoform and methylene iodi centrifugation. Samples of 4·5, 3·8, and 2·5 grams were sent for analysis.

The advantage of the rather lengthy method is the avoidance of contaminati of the sample during pulverization and the prevention of leaching of alkalis water during the purification. As no heat was used, the water content w unaffected by the preparation. The importance of these precautions is not generally recognized and many of the analytical data recorded in the literat are invalidated by faulty procedure. The effect of water on a mineral can

onstrated by grinding a little biotite to a fine powder and adding water and op of colourless phenolphthalein solution. A pink coloration forms, indicating solution of alkalis by water at room-temperature due to the action of the ogen ion. The leaching power of the hydrogen ion increases with the tempera- and acidity. The use of inert liquids for separation purposes though accepted rinciple has not always been strictly kept. All liquids with a water base, Clerici solution, should be avoided. Some workers in attempting to purify mineral have digested the sample with acid, a drastic treatment which is oubt responsible for many of the low alkali values recorded in the literature.

III. *Determination of optical data and specific gravities.*

he refractive indices were determined by the immersion method using an e refractometer and a sodium lamp. The grains were splintered in oil under microscope, using a fine needle. With careful manipulation it was possible elect and set up favourable grains with (010), (001), and (100) surfaces. On e the indices α, β, and γ were determined in duplicate, each on two surfaces. mean results recorded in table I are believed to be accurate to $\pm 0{\cdot}001$.

he optic axial angles were measured on the universal stage following Reinhard[1] he methods of adjustment to ensure correct centring and height. The observed es were corrected graphically for the differences in refractive indices between mineral and the glass segments of the universal stage. The results tabulated the averages of six values in each case and represent an accuracy of $\pm 2°$. les calculated from the refractive indices by a graphical method[2] were in e agreement. The extinction-angle for cummingtonite was measured on the ersal stage using the method of Burri.[3]

he specific gravities of grains of each analysed mineral were determined by tion in mixtures of methylene iodide and carbon tetrachloride.[4]

IV. *Results and their interpretation on the basis of atomic constitution.*

he results of the chemical analyses, specific gravity, and the optical data ined from the minerals sent for analysis are given in table I. It is, of course, ossible to calculate the number of oxygen atoms including hydroxyl groups tly from the chemical analyses and specific gravities without X-ray measure- ts of the unit-cell dimensions of the analysed specimens. However, assuming land's[5] X-ray data for cummingtonite, the number of oxygen and hydroxyl ps is approximately 48 per unit cell. Table II gives the atomic constitution he analysed specimens based on $24(O+OH)$, that is half the ideal oxygen roxyl content of the unit cell. The results are in good agreement with ren's[6] formula for amphiboles with low (Ca,Na) content,

$$(Mg,Fe'',Ti,Al,Mn,Ca,Na)_7(Si,Al)_8O_{22}(OH)_2.$$

[1] M. Reinhard, Universal Drehtischmethoden. Basel, 1931. [M.A. **4**–435.]
[2] J. H. Lane and H. T. U. Smith, Amer. Min., 1938, vol. 23, p. 457. [M.A. **7**–249.]
[3] C. Burri, Schweiz. Min. Petr. Mitt., 1931, vol. 11, p. 285. [M.A. **5**–71.]
[4] F. A. Bannister and M. H. Hey, Min. Mag., 1931, vol. 22, p. 573.
R. G. Wayland, Amer. Min., 1936, vol. 21, p. 610. [M.A. **7**–26.]
[5] B. E. Warren, Zeits. Krist., 1930, vol. 72, p. 516. [M.A. **4**–278.]

Recorded cummingtonites and gedrites show $(Ca,Na)_n$ where n is much le than 2, and are low to moderately aluminous or aluminoferric. The Al-ato are partly in 4-fold co-ordination (replacing Si-atoms) and partly in 6-fo co-ordination (replacing Mg, Fe, Mn, &c.). Analyses I, II, and III computed the basis of (O,OH) = 24 show the (Ca,Na) total to be much below 2 in all cas Analysis I is in good agreement with previously recorded cummingtonit Analysis III, the most aluminous and correspondingly least magnesic variety, more appropriately compared with gedrite. Analysis II occupies an intermedia position between I and III.

Table I. Analyses, optical data, and specific gravities of cummingtonite and gedrite from Strathy, Sutherland.

	I.	II.	III.
SiO_2	51·53	49·60	44·70
TiO_2	0·31	0·26	0·57
Al_2O_3...	5·02	8·65	14·72
Fe_2O_3	0·82	0·48	1·62
FeO	16·91	18·54	18·96
MnO	0·22	1·08	0·21
MgO	20·84	16·78	14·89
CaO	1·34	0·97	0·69
Na_2O	0·65	0·79	1·34
K_2O	nil	nil	nil
P_2O_5	—	0·34	—
H_2O+ 105° C.	2·15	2·52	2·27
H_2O- 105° C.	0·64	0·29	0·29
	100·43	100·30	100·26
Sp. gr.	3·10	3·18	3·24
2V	75°	75°	85°
Sign	positive	positive	positive
$\gamma:c$	20°	19°	0°
α	1·643	1·645	1·652
β	1·650	1·652	1·656
γ	1·663	1·664	1·666
$\gamma-\alpha$	0·020	0·019	0·014
Pleochroism:			
α	almost colourless	pale yellow	yellow
β	very pale brown	pale brown	brownish
γ	very pale violet	pale violet	smoke-grey

I. Pale cummingtonite from oligoclase-biotite-rutile-schist. NW. end of Geodh Du NNW. Strathy Point. Analyst, Geochemical Laboratories.

II. Dark cummingtonite from oligoclase-quartz-magnetite-granulite. 150 yards south Toll Egain, NNE. Strathy Point. Deducting apatite, CaO 0·52 %. Analy Geochemical Laboratories.

III. Gedrite from oligoclase-quartz-biotite-garnet-schist. East side of Uamh nan Soithiche NW. of Armadale. Analyst, Geochemical Laboratories.

TABLE II. Computation of the chemical analyses to the basis of (O,OH) = 24.

	I, Pale Cummingtonite.				II, Dark Cummingtonite.				III, Gedrite.			
...	... 7·36	8·00			7·16	8·00			6·47	8·00		
...	... 0·64				0·84				1·53			
...	... 0·21				0·63				0·98			
...	... 0·09				0·05				0·18			
...	... 2·02	6·82			2·24	6·64			2·29	6·75		
...	... 0·03		7·21		0·13		6·94		0·03		7·24	
...	... 4·44				3·56				3·21			
...	... 0·03				0·03				0·06			
...	... 0·21	0·39			0·08	0·30			0·11	0·49		
...	... 0·18				0·22				0·38			
...	... 21·95	24·00			21·57	24·00			21·83	24·00		
...	... 2·05				2·43				2·17			

Although the basis of computation ensures that the positive (cation) charges exactly balance the negative (anion) charges, it is noteworthy that the proportion of (OH)-groups for the computed constitutions (based on the analyst's findings for water above 105° C.) are very close to the $(OH)_2$ required by the theoretical relationship $O_{22}(OH)_2$. Unfortunately, the determination of the fitting curves, for use in checking the validity of the assumption that water above 105° C. represents the (OH) content of the mineral, still remains to be done.

V. *Correlation of optical properties with chemical composition.*

The two cummingtonites have very similar optical properties. The optical properties of the gedrite are closely related to those of the cummingtonites, but there are certain important differences best seen by comparing the α values, and the birefringences. In the gedrite β is nearer to α, $\gamma - \alpha$ is smaller, and the optic axial angle is considerably larger. In the orthorhombic gedrite the *c*-axis corresponds to γ; in the monoclinic cummingtonites $\gamma : c = 20°$ maximum.

Research of the literature yielded few satisfactory sets of chemical and optical data which had been made on the same sample of material. Some workers performed detailed analyses on the minerals from one locality and quoted optical data obtained from specimens obtained elsewhere; others give detailed optical data accompanied by only partial analyses. From the mass of data examined four analyses of cummingtonites and four of gedrites have been chosen for comparison with the Strathy samples (tables III and IV).

Correlating optical properties with chemical composition, one observes that the mineral with the highest iron content has the highest refractive indices, and the minerals with high alumina content have the lowest birefringences. The effect of the R_2O_3 radicle in decreasing the birefringences has been demonstrated in the pyroxene series.[1] An increase in alumina at the expense of iron in members of the epidote group reduces both the refractive indices and the birefringences. Members of both the calcium-poor amphibole series and in the epidote series

[1] A. N. Winchell, Elements of optical mineralogy. New York, 1933, pt. 2, p. 230.

Table III. Analyses and optical data of cummingtonites.

	A.	B.	C.	D.	E.
SiO_2	51·53	54·28	50·99	53·12	50·70
TiO_2	0·31	0·02	0·02	0·21	0·31
Al_2O_3	5·02	1·26	3·78	2·78	1·72
Fe_2O_3	0·82	0·80	0·85	0·25	3·11
FeO	16·91	21·79	21·70	22·46	26·63
MnO	0·22	0·26	0·18	0·27	0·19
MgO	20·84	18·64	18·61	15·46	14·36
CaO	1·34	0·15	—	2·26	0·87
Na_2O	0·65	0·14	0·24	—	0·60
K_2O	nil	trace	0·31	—	0·15
H_2O+	2·15	2·16	2·77	3·33	1·46
H_2O-	0·64	—	—	—	—
F	—	0·57	—	—	—
	100·43	100·07	99·45	100·14	100·10
Sp. gr.	3·10	3·241	—	—	3·307
2V	75°	68°	65°	—	—
Sign	positive	positive	positive	—	—
$\gamma:c$	20°	20°	20°	19°	—
α	1·643	1·639	1·640	1·643	α'1·661
β	1·650	1·647	1·647	—	—
γ	1·663	1·664	1·665	1·670	γ'1·681
$\gamma-\alpha$	0·020	0·025	0·025	0·027	0·020

A. Strathy, Sutherland. R. S. Collins, 1942. Analyst, Geochemical Laboratories.

B. Saude, Ryfylke, Norway. N. Sundius, Min. Petr. Mitt. (Tschermak), 1933, vol. 4 p. 425. [M.A. **3**–153, **6**–64.] Analyst, A. Bygdén.

C. Odalfältet, Persberg, Sweden. H. E. Johansson, Geol. För. Förh. Stockholm, 191 vol. 36, p. 454. Analyst, N. Sahlbom.

D. Kenidjack, Cornwall. C. E. Tilley and J. S. Flett, Summ. Progr. Geol. Surv. Gre Britain, 1930, for 1929, pt. 2, p. 31. [M.A. **4**–402.]

E. Isopää, Finland. P. Eskola and T. Kervinen, Compt. Rend. Soc. Géol. Finlande, 193 no. 9, p. 482. [M.A. **7**–26.] Analyst, T. Kervinen.

increase in alumina content makes β approach more closely to a midway positio between α and γ, $\beta-\alpha$ and $\gamma-\beta$ decreasing and approaching each other. Winche (loc. cit., p. 239) considers that an increase in soda content leads to a mo asbestiform mineral. As the Strathy results indicate quite the opposite tendenc the Na-rich member being the most robust, Winchell's view cannot be appli here. It may, however, be mentioned that the more asbestiform a miner becomes, the more difficult it is to prepare a pure sample for analysis.

Winchell (loc. cit., pp. 242, 244), Sundius,[1] and Alling[2] plot the optical pr perties against percentages of 'minals', which Alling claims give a clearer pictu than do the complex mineral compounds. In nature no pure 'minals' exi They are hypothetical compounds and the suitability of plotting optical properti against them is doubtful. The 'minal' method shows a definite trend, increa of iron content causing increase in refractive indices, but beyond this its utili is doubtful.

[1] N. Sundius, Über die Mischungslücken zwischen Anthophyllit-Gedrit-Cummingto Grünerit und Tremolit-Aktinolith. Min. Petr. Mitt. (Tschermak) 1933, vol. 43, p. 427. [M **6**–64.]

[2] H. L. Alling, Interpretative petrology. New York, 1936, p. 111.

TABLE IV. Analyses and optical data of gedrites.

	F.	G.	H.	I.	J.
SiO_2	44·70	44·09	46·50	44·22	43·70
TiO_2	0·57	0·31	0·89	—	0·55
Al_2O_3	14·72	17·22	15·48	23·79	10·88
Fe_2O_3	1·62	1·87	0·89	0·20	3·52
FeO	18·96	15·02	16·01	9·21	26·53
MnO	0·21	0·14	nil	0·16	0·24
MgO	14·89	17·12	17·62	20·69	11·48
CaO	0·69	0·51	0·81	0·62	0·54
Na_2O	1·34	1·24	0·77	—	1·24
K_2O	nil	trace	0·12	—	0·15
H_2O+	2·27	2·03	1·19	1·42	1·21
H_2O-	0·29	nil	—	—	—
	100·26	99·55	100·28	100·31	100·04
Sp. gr.	3·24	3·259	—	3·178	3·371
2V	85°	—	78°	large	—
Sign	positive	positive	positive	negative	—
α	1·652	1·651	1·642	1·642	α'1·674
β	1·656	—	1·648	1·655	—
γ	1·666	1·672	1·658	1·661	1·697
$\gamma-\alpha$	0·014	0·021	0·016	0·019	0·023

Strathy, Sutherland. R. S. Collins, 1942. Analyst, Geochemical Laboratories.

Terbeostrov, Karelia. C. E. Tilley, Geol. Mag., 1939, vol. 76, p. 327. [M.A. **7**-445.] Analyst, H. C. G. Vincent.

Terbeostrov, Karelia. N. A. Ignatiev, Trav. Inst. Pétrogr. Acad. Sci. U.S.S.R., 1934, no. 6, p. 65. [M.A. **6**-419.]

Mason's Mountain, North Carolina. E. P. Henderson, Amer. Min., 1931, vol. 16, p. 566. [M.A. **5**-76.] Analyst, E. P. Henderson.

Isopää, Finland. P. Eskola and T. Kervinen, Compt. Rend. Soc. Géol. Finlande, 1936, no. 9, p. 482. [M.A. **7**-26.] Analyst, T. Kervinen.

undius states that anthophyllite (including gedrite) and cummingtonite are dimorphous. He demonstrates with the best analyses at his disposal that a % molecular increase in Al_2O_3 and Fe_2O_3 transforms the monoclinic into orthorhombic amphibole, which is in accord with the results from Strathy. chell (loc. cit., p. 240) believes the calcium-poor amphiboles to be isodimor- us; he ignores alumina, over-emphasizing the iron oxides and magnesia, treats theoretical 'minals' as actual mineral modes. Kunitz,[1] Winchell, and g are wrong in their belief that cummingtonite, anthophyllite, and gedrite one homogeneous series.

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[1] W. Kunitz, Neues Jahrb. Min., Abt. A, 1930, vol. 60, p. 190. [M.A. **4**-200.]

Chemical data on a silica-poor argillaceous hornfels and its constituent minerals.

By F. H. Stewart, B.Sc., Ph.D.

[Read June 4, 1942.]

THE hornfels discussed here was collected from Sparcraigs, near Whitecairn eight miles to the north of Aberdeen, very close to the eastern contact of t basic igneous intrusion of Belhelvie. The Highland Schists of the district a very poorly exposed, but at this locality there are a few small isolated outcro of high-grade hornfels, nearly all silica-poor types, with garnet, spinel, hypersthen cordierite, plagioclase, and biotite as their chief mineral constituents. T actual contact is obscured, but the igneous rock, an olivine-gabbro, is expos at about twenty yards from the hornfels.

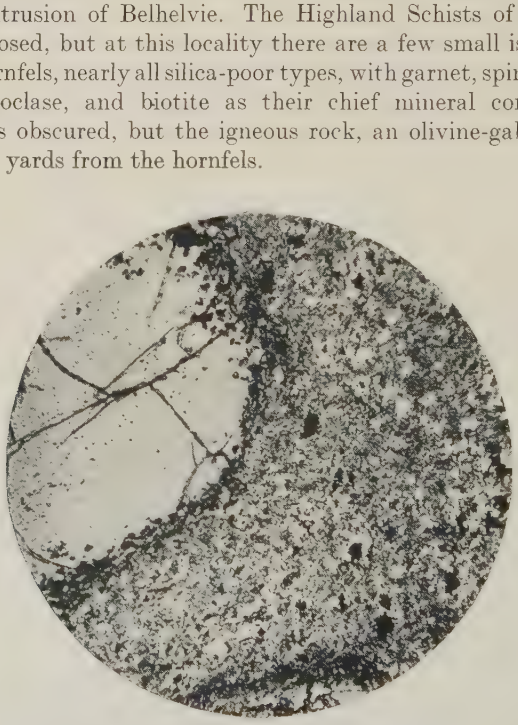

Fig. 1. Garnet-spinel-cordierite-plagioclase-biotite-hornfels. Sparcraigs, Belhelvie, Aberdeenshire. ×15.

The hornfels on which this work has been done forms a fairly homogeneo band, about a foot in thickness, associated with closely related types. Fre deep-red garnets, up to five millimetres in diameter, are scattered fairly ever through the rock, and are set in a dark fine-grained base. The constitue minerals are garnet, spinel, cordierite, plagioclase, biotite, magnetite, a pyrrhotine, with a very little sillimanite and some orthoclase. In slice (fig. the garnet forms large porphyroblasts, their rims crowded with small biot flakes and iron-ore grains, with a few irregular grains of spinel. The interi are relatively free from inclusions, but may contain patches of biotite flakes a

-ore crystals. A few small idioblastic garnets occur in the groundmass. p-green spinel forms irregular microporphyroblastic grains, up to 0·4 mm. ameter, distributed evenly through the slice, and often associated with iron-

The finer-grained groundmass is composed chiefly of abundant biotite, ierite, and plagioclase, with small grains of spinel and ore. The cordierite ften sector-twinned, and shows few haloes. It is optically positive. The ioclase is andesine-labradorite, about Ab_1An_1, and is often untwinned. e orthoclase has been observed in this groundmass, and a few tiny silli-ite needles.

n analysis of this rock is given in table I, with the measured mineral pro-ions. As it was found impossible to measure the relative proportions of ierite and plagioclase, the plagioclase percentage was calculated from the es for CaO and Na_2O in the analysis. This was deducted from the measured entage of the colourless constituents, and the remainder was allotted to ierite, the small amount of orthoclase being neglected.

he garnet, spinel, cordierite, and biotite of this hornfels have been separated analysed, and the analyses and atomic proportions are shown in tables II-V, the optical properties of the minerals. The garnet was separated by hand-ing and by the centrifuge. The spinel was separated by centrifuging with

TABLE I. Garnet-spinel-cordierite-plagioclase-biotite-hornfels, Sparcraigs, Belhelvie, Aberdeenshire. (Analyst, F. H. Stewart.)

...	...	...	40·77	Na_2O	...	...	1·09	Garnet	11
...	...	...	2·13	K_2O	...	...	2·73	Spinel and ore	6
3	...	...	25·90	H_2O+	...	...	0·97	Biotite	42
3	...	...	1·02	H_2O-	...	...	0·26	Cordierite	21
...	...	...	17·52	P_2O_5	...	...	0·02	Plagioclase (calculated)	20
...	...	...	0·24	Total ...	...	...	99·67		100
...	...	...	4·95						
...	...	...	2·07						

Measured mineral proportions.

TABLE II. Garnet from silica-poor hornfels, Sparcraigs, Belhelvie, Aberdeenshire. (Analyst, F. H. Stewart.)

				Wt. %.		Molecular ratios.		No. of metal atoms to 12 oxygens.		
...	...	...	...	36·56	...	0·6087	Si	... ...	2·948	2·979
...	...	...	...	0·51	...	0·0064	Ti	... ...	0·031	
3	...	...	...	21·07	...	0·2067	Al	... ...	2·001	2·029
3	...	...	...	0·47	...	0·0029	Fe'''	... ...	0·028	
...	...	...	...	33·51	...	0·4665	Fe''	... ...	2·259	2·998
	...	...	...	1·81	...	0·0255	Mn	... ...	0·124	
..	...	...	...	3·97	...	0·0982	Mg	... ...	0·476	
	...	...	...	1·61	...	0·0287	Ca	... ...	0·139	
ta	...	...	...	99·51			O	... ...	12·000	

Almandine	...	...	77·85			
Pyrope	...	...	13·26			
Spessartine	...	...	4·24	n	... ...	1·801±0·002 (Na)
Grossular	...	...	3·04	Sp. gr.	...	4·12
Andradite	...	...	1·61			

Clerici solution, but it was found impossible to free the material from composi garnet-spinel grains, and the analysis has been recalculated after subtracti of the garnet impurity (see table III). The cordierite and biotite were separat by the centrifuge and the Evans's electromagnetic separator (Min. Mag., 19 vol. 25, p. 474), and the analysed material was practically free from impuriti

The refractory nature of the spinel made the determination of FeO rath difficult. The normal method was used (Washington, 1930, pp. 213–216), t mineral being decomposed by HF and H_2SO_4. Ten determinations were mad using 0·05 gram of material for each. In all cases there was incomplete deco position, and the residues were filtered, washed, and treated again. In ea determination there was complete decomposition after the third treatment. T values obtained varied between 37·51 and 35·79, with an average value of 36·50 %

TABLE III. Spinel (hercynite) from silica-poor hornfels, Sparcraigs, Belhelvie, Aberdeen shire. (Analyst, F. H. Stewart.)

	Wt. %.	Wt. % recalculated after subtraction of garnet impurity.	Molecular ratios.	No. of metal atoms to 4 oxygens.	
SiO_2	2·69	—	—		—
TiO_2	0·63	0·64	0·0080	Ti 0·014	
Al_2O_3	50·56	53·02	0·5201	Al 1·824	1·9
Fe_2O_3	6·62	7·12	0·0446	Fe‴ 0·156	
FeO	36·50	36·83	0·5127	Fe″ 0·899	
MnO	0·16	0·02	0·0003	Mn 0·001	1·0
MgO	2·48	2·37	0·0588	Mg 0·103	
CaO	0·10	—	—	O 4·000	
Total	99·74	100·00			
n	>1·80				
Sp. gr.	4·21.				

The only impurity was garnet, the composition of which was calculated (on the basis 2·69 % SiO_2) from the analysis in table II.

TABLE IV. Cordierite, from silica-poor hornfels, Sparcraigs, Belhelvie, Aberdeenshire. (Analyst, F. H. Stewart.)

	Wt. %.	Molecular ratios.		No. of metal atoms to 18 oxygens.	
SiO_2	47·69	0·7940	Si	4·987	5·0
TiO_2	trace	—	Al	4·007	
Al_2O_3	32·52	0·3190	Fe‴	0·049	4·0
Fe_2O_3	0·63	0·0039	Fe″	0·703	
FeO	8·04	0·1119	Mn	0·004	
MnO	0·04	0·0006	Mg	1·178	1·9
MgO	7·56	0·1875	Ca	0·058	
CaO	0·52	0·0093	O	18·000	
Na_2O	0·53	0·0085	Na_2O	0·053	
K_2O	0·42	0·0045	K_2O	0·028	
H_2O+	1·85	0·1027	H_2O	0·837	
H_2O-	0·55	0·0305			
Total	100·35				
α	1·538	± 0·002 (sodium-light)	$\gamma-\alpha$	0·009	
β	1·542		2V	84°, posit	
γ	1·547		Sp. gr.	2·64	

TABLE V. Biotite, from silica-poor hornfels, Sparcraigs, Belhelvie, Aberdeenshire. (Analyst, F. H. Stewart.)

	Wt. %.	Molecular ratios.		No. of metal atoms to 12 (O,OH,F).	
... ...	34·87	... 0·5806	Si	2·665	4·000
... ...	5·12	... 0·0641	Al	1·782	
... ...	19·79	... 0·1941	Ti	0·294	2·823
... ...	1·72	... 0·0108	Fe‴	0·099	
... ...	17·79	... 0·2477	Fe″	1·137	
... ...	0·02	... 0·0003	Mn	0·001	
... ...	7·42	... 0·1841	Mg	0·845	
... ...	0·54	... 0·0096	Ca	0·044	0·940
... ...	0·67	... 0·0108	Na	0·099	
... ...	8·18	... 0·0868	K	0·797	
... ...	2·89	... 0·1604	OH	1·472	1·573
... ...	0·29	... 0·0161	F	0·101	
... ...	0·42	... 0·0110			
tal	99·72				
O for F	0·18				
	99·54				

α	1·603	±0·002 (sodium-light)
β	1·660	
γ	1·661	
γ—α	0·058	

α Light yellow

β, γ Brown with reddish tinge

n each of these four minerals FeO and MgO may replace each other, and it is r interesting to note the selective distribution of these constituents. The : MgO ratios are shown in table VI, with the weight percentages.

TABLE VI.

	Wt. % FeO.	Wt. % MgO.	Weight FeO:MgO.	Molecular FeO:MgO.	Wt. % Fe_2O_3.
pinel	36·83	2·37	15·54	8·72	7·12
arnet	33·51	3·97	8·44	4·75	0·47
iotite	17·79	7·42	2·40	1·35	1·72
ordierite	8·04	7·56	1·06	0·60	0·63

ne FeO: MgO ratio in the spinel is remarkably high, and if we included O_3, which is given in column five, it would be considerably higher still in tion to the ratios in the other minerals. A dark-green spinel from an aluminous blith in tholeiite from Mull (Thomas, 1922, p. 247) is considerably more mesian, but contains quite a large amount of Fe_2O_3 (4·26 %).

ne above results are comparable to those obtained by Folinsbee (1941*a*, 2) from the minerals of an injection-gneiss near Great Slave Lake. He found t the garnet, cordierite, and biotite of this rock had the following compositions:

Garnet	24·0 % $Mg_3Al_2Si_3O_{12}$,	74·0 % $Fe_3Al_2Si_3O_{12}$
Biotite	39·9 % $KMg_3AlSi_3O_{10}(OH)_2$,	60·1 % $KFe_3AlSi_3O_{10}(OH)_2$
Cordierite	61·0 % $Mg_2Al_4Si_5O_{18}$,	39·0 % $Fe_2Al_4Si_5O_{18}$

g rnet and cordierite were analysed, and the composition of the biotite was n d by 'optical analysis'. The ratios agree fairly well with those of the elvie minerals, although the garnet is more magnesian, and the biotite

slightly less so, while the cordierite has almost the same ratio as the Belhelv cordierite.

It may be noted that practically all the MnO of the Sparcraigs hornfels contained in the garnet:

	Garnet.	Spinel.	Cordierite.	Biotite.
Wt. % MnO	1·81	0·02	0·04	0·02

This is of interest in view of the fact that Tilley (1926) has suggested that hig manganese content promotes the formation of garnet in pelitic contact-zone The manganese content of this garnet is, of course, comparatively low, and it considered that other factors have played their part in promoting its formati in this particular case. The writer hopes to discuss this question in a lat communication.

The TiO_2, as would be expected, is chiefly contained in the biotite, whi differs from most analysed biotites in the combination of high TiO_2 and hig Al_2O_3. Only two analyses of biotite from thermally metamorphosed rocks ha been found in the literature—one from the Oslo district (Lang, 1886, p. 31 and the other from a cordierite-biotite-hornfels from Japan (Tsuboi, 193 p. 128). These analyses show high Al_2O_3, but comparatively low TiO_2 conte The FeO: MgO molecular ratios are: Oslo, 1·52; Belhelvie, 1·35; Japan, 0·96.

The cordierite of this rock is peculiar in being an optically positive variet Twelve records and six analyses of positive cordierites have been found in t literature, and five of these analyses are given in table VII. The sixth (Chack 1916) is not quoted, as it shows 5·65 % Fe_2O_3.

Table VII. Optically positive cordierites.

	A.	B.	C.	D.	E.	F.
SiO_2	48·37	50·09	50·15	47·96	48·19	47·69
TiO_2	—	—	0·38	nil	0·01	trace
Al_2O_3	29·22	31·78	33·07	31·52	33·45	32·52
Fe_2O_3	2·20	0·78	1·52	1·03	0·55	0·63
FeO	7·07	8·71	2·22	3·24	8·40	8·04
MnO	0·42	nil	0·12	1·09	0·18	0·04
MgO	9·54	6·69	11·01	12·16	7·95	7·56
CaO	1·92	—	0·29	nil	0·17	0·52
Na_2O	—	—	0·14	0·33	0·22	0·53
K_2O	—	0·07	0·08	trace	0·02	0·42
H_2O	1·84	1·43	1·46	2·80	0·68	2·40
Total	100·58	99·55	100·44	100·13	99·82	100·35
Sp. gr.	2·598	2·65	2·588	—	2·631	2·64
$2V_\gamma$	81–95°	88° 31′	88° 6′	76°	85–95°	84°
α	—	1·543	1·527	1·534	1·544	1·538
β	—	1·548	1·532	—	1·550	1·542
γ	—	1·553	1·538	1·543	1·556	1·547
$\gamma-\alpha$	—	0·010	0·011	0·009	0·012	0·009

A. Madura district, Madras, India (Krishnan, 1924).
B. Santavuori, Ilmajoki, Finland (Pehrman, 1932).
C. Attu, Finland (Pehrman, 1932).
D. Cape Denison, Antarctica (Tilley, 1940).
E. Great Slave Lake (Folinsbee, 1941).
F. Sparcraigs, Belhelvie.

nese analyses show a wide variation in chemical composition. C and D are y magnesian types, and agree with the suggestions of Shibata (1936, 23–224) and Winchell (1937, pp. 1176–1177) that iron-poor cordierites may tically positive, although their optic axial angles give points which lie rather e the curves in the diagrams given by these authors. The other cordierites ble VII, however, are much richer in iron, and on the basis of the diagrams ibata and Winchell they should have negative axial angles of about 45–50°. analyses can all be closely matched by analyses of negative cordierite, and otal variation ranges of the oxides are roughly the same in both cases. The ally positive cordierites show a tendency to have lower refractive indices birefringence than negative types of similar MgO: FeO ratio, and Folinsbee *b)* suggests that this is due to a low alkali and high alkali-earth content e positive types. However, it seems rather unlikely that an increase in i-content would have the effect of raising the indices and birefringence in comagnesian mineral like cordierite, and from an examination of the avail- data the writer cannot agree with this suggestion. A comparison of the ses E and F, which have very similar FeO: MgO ratios, points rather in the site direction, but the low water-content of analysis E is perhaps the deciding r in this case. Folinsbee has suggested that the variation of the optic axial may largely depend on the content of alkalis and lime, and gives diagrams ow that the optic axial angle decreases with increase of alkalis and with ase of lime. He finally obtains a curve showing a marked decrease of optic angle with increase of Na_2O+K_2O-CaO. When analyses D and F of VII are plotted on this diagram, it is found that their axial angles are 0° too high, and in view of the small number of points plotted, and the fact they are considerably scattered, the shape of the curve depends almost ly on one isolated point at the alkali-rich end. The writer considers that ata are insufficient for determination of the true relations.

appears, then, that no single replacement series can account for the anomalous tion of the optic axial angle. There are so many variables in the cordierite ula that the scarcity of complete and reliable analyses makes it impossible ve the problem at present.[1]

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References

3 Lang (H. O.). Nyt Mag. Nat., vol. 30, p. 318.
3 Chacko (I. C.). Geol. Mag., dec. 6, vol. 3, pp. 462–464. [M.A. 1–66.]
2 Thomas (H. H.). Quart. Journ. Geol. Soc. London, vol. 78, p. 247. [M.A. 2–304.]
4 Krishnan (M. S.). Min. Mag., vol. 20, pp. 248–251.
5 Tilley (C. E.). Min. Mag., vol. 21, pp. 47–50.

ne effects of the water-content, and of an isomorphous substitution of silicon and mag- for aluminium, on the optical properties of cordierite, have been discussed in a recent Thiele (1940). Several new analyses are given and these are quoted by Folinsbee) Unfortunately Thiele's paper is not available to the writer, but from an examination published analyses of cordierite it is considered that here again the data are insufficient to much light on the subject.

1930 Washington (H. S.). The chemical analysis of rocks. 4th edition, pp. 213–216. N York.
1932 Pehrman (G.). Acta Acad. Aboensis, Math. Physica, vol. 6, no. 11, 12 pp. [M.A 383.]
1936 Shibata (H.). Japanese Journ. Geol. Geogr., vol. 13, pp. 205–227. [M.A. **6**–479.]
1937 Winchell (A. N.). Amer. Min., vol. 22, pp. 1175–1179. [M.A. **7**–208.]
1938 Tsuboi (S.). Japanese Journ. Geol. Geogr., vol. 15, p. 128. [M.A. **7**–183.]
1940 Thiele (E.). Chemie der Erde, vol. 13, pp. 64–91. [M.A. **8**–162.]
1940 Tilley (C. E.). Rept. Australasian Antarct. Exp., ser. A, vol. 4, pp. 339–344.
1941*a* Folinsbee (R. E.). Amer. Min., vol. 26, pp. 50–53. [M.A. **8**–225.]
1941*b* —— Amer. Min., vol. 26, pp. 485–500. [M.A. **8**–227.]